THE

RAILROAD ENGINEER'S PRACTICE,

BEING

A SHORT BUT COMPLETE DESCRIPTION OF THE DUTIES OF THE YOUNG ENGINEER IN PRELIMINARY AND LOCATION SURVEYS, AND IN CONSTRUCTION.

BY

THOMAS M. CLEEMANN, A. M., C. E.

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ERRATA.

On page 14, line 4, for $1\frac{1}{4}$ read $\frac{1}{4}$.

On page 26, line 2 from bottom, for $\frac{1}{2}$ read $1\frac{1}{2}$.

On page 52, lines 7, 9 and 11, for W read W'; in lines 8 and 10 the printing is not

ERRATA.

On p. 39, l. 8 from bottom, for "less" read "more," and the next sentence may then be left out.

On p. 49, l. 2 from top, "The maximum compression on $D\,B = \frac{1 \times 2}{2 \times n} W' \sec.\,\theta$" should have added to it, "$- \frac{n-3}{2} W \sec.\,\theta$ if a plus quantity; if it is a minus quantity, there will be no compression on $D\,B$."

On p. 49, l. 7 from top, "The maximum tension on $B\,C = \frac{2 \times 3}{2\,n} W' \sec.\,\theta$" should have added to it "$- \frac{n-5}{2} W \sec.\,\theta$ if a plus quantity."

On p. 49, l. 8 from top, "The maximum compression on $C\,I = \frac{3 \times 4}{2\,n} W' \sec.\,\theta$" should have added to it "$- \frac{n-7}{2} W \sec.\,\theta$ if a plus quantity."

On p. 49, l. 12 from top, "The maximum tension on $I\,L = \frac{4 \times 5}{2\,n} W' \sec.\,\theta$" should have added to it "$- \frac{n-9}{2} W \sec.\,\theta$ if a plus quantity."

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On page 52, lines 7, 9 and 11, for W read W'; in lines 8 and 10 the printing is not clear; in each one the first term of the second member of the equation is W, and the second term W'.

On page 54, lines 9 and 11, place a figure 2 before W and W'.

On page 55, line 8 from bottom, after "total width" read "or depth (whichever is the least)."

On page 57, in the lower figure, the letter L is left out; it should be just above the letter A.

the Chief Engineer under whom the writer began the practice of his profession, on the Pennsylvania Railroad, and whose uniform kindness and interest in his welfare have been continual causes of pleasure and gratitude, this book is respectfully dedicated by T. M. C.

Atkin & Prout, Printers, No. 12 Barclay Street,
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TO

W. H. WILSON, Esq.,

the Chief Engineer under whom the writer began the practice of his profession, on the Pennsylvania Railroad, and whose uniform kindness and interest in his welfare have been continual causes of pleasure and gratitude, this book is respectfully dedicated by T. M. C.

PREFACE.

The present work is intended to fill a want that the writer himself acutely felt on beginning his professional career. There were many points of practice of which he could only get information by observation and experience, involving a loss of time, which might have been saved to him, could he have referred to some book which would have told him how certain problems had been solved by other engineers, and which would have prepared him the better to observe the methods pursued by those with whom he was thrown in executing their work.

Some of those who approve the intention of the book, may think that too much detail has been entered into, and that much that is specified can be more quickly and better learned in the field. To such it is replied that it is extremely difficult to tell the proper point at which to stop in minute description, and that if the author has erred in minuteness, it is at least a fault on the proper side; he will be satisfied if he has left nothing essential out. In regard to the methods of organizing parties, keeping field books, staking out, etc., there are very great differences among engineers; the author has merely given what he individually considered the best.

The subject of iron bridges has not been touched upon, because it would add very considerably to the bulk of the book. If, however, this first venture of the author should prove a success, he hopes to devote a special book to the subject of bridges, in which an attempt will be made to treat of the various details that are employed, in an exhaustive manner, as well as to discuss the strains in the different "skeleton" structures.

The author has freely quoted from the "Engineer's Pocket Book," of Mr. Trautwine, which he hopes will be in the library of every engineer who may possess the present work. He considers no other book to have appeared which supplies so well a

constant want of the engineer at all stages of his career, and he is happy to be able to state that Mr. Trautwine himself gave him permission to extract from it what he desired for the present book.

He has tried to give credit to those from whom he has obtained information, but as much of his material has been obtained from conversations with other engineers, notes of which were made for his own convenience only, at a time when he did not expect to put them in book form, he cannot always recall to whom he is indebted. If any of his friends, however, remember giving him any practical rules which are not acknowledged, he will be obliged if they will notify him of the fact.

340 South Twenty-first Street,
Philadelphia, October, 1879.

TABLE OF CONTENTS.

PRELIMINARY SURVEY.

The Chief Engineer, from an inspection of the various maps of the country he can obtain, and a personal examination of the ground, decides where it will be necessary to run lines to determine which is the cheapest that can be built, and gives the necessary orders for such lines to the Principal Assistant Engineers.

The method pursued by the Principal Assistant Engineer differs according to the character of the country, and the time that can be devoted to the preliminary survey. A quick, rough method of gaining the requisite information for the location will first be given, and afterward, one more exact—that pursued on the Bennett's Branch Extension of the Allegheny Valley Railroad. The latter is especially recommended where the means of the company will admit of the more accurate work, and where it may not be a matter of policy to begin the construction of the road at the earliest possible moment.

Each Principal Assistant organizes a party which consists as follows : Principal Assistant, Transitman, Leveller, Topographer, Level Rodman, Slope Rodman, Flagman, two Chainmen, three or more Axemen. An Axeman provides a number of stakes in advance and numbers them consecutively from 0, shaving off a smooth place for that purpose, and drives the first one—usually driven flush with the ground,

and called a "plug"—at the place indicated by the Principal Assistant. The latter then starts ahead with the Flagman, and the Transitman sets his transit over the first stake or plug. The Principal Assistant, having decided where he wishes to run the line, sets up the flag. The Chainmen instantly begin chaining toward it, the hind one "lining" the head one, and an Axeman driving the stakes, one every 100 feet, in the order of marking. The Transitman takes his sight, reads only the needle to quarter degrees, records the reading, and starts off for the flag. On arriving there, he sets up ready for another sight, which the Principal Assistant is ready to give him, by waving his handkerchief if the Flagman has not had time to come up. In an open country, the speed of the Chainmen should govern the speed of the party. When there is much underbrush, the Principal Assistant may require several Axemen to clear the way.

The Leveller follows the Transitman as closely as possible, taking levels on every stake, and, if necessary, on abrupt intermediate changes of the slope. His Axeman makes "pegs" (or turning points) and cuts down brush obstructing his view.

The Topographer follows a day behind the Transitman and Leveller. He is provided with a thin box, with a hinged cover on the end, which serves both as a portfolio and a drawing-board. There should be some oiled cloth fastened to it for keeping the paper dry. The paper is tacked to the board with thumb tacks; a convenient size of sheet is 21 × 16 inches. The Topographer has obtained at night from the Transitman and Leveller their notes of the day, and plotted the line on a scale of 400 feet to the inch, noting the elevations at the stations. He takes this into the field with him. His Slope Rodman and Axeman go ahead and measure the transverse slopes, laying a rod upon the ground at each station, and upon it a clinometer;

with a tape they measure the distance to where the slope changes, and then measure the new slope and its length, and so on. This is done on each side of the line, and is noted in the Rodman's book in one of two ways: the direction of the slope being indicated either by the signs + and —, or by the inclination of the line dividing the numerator from the denominator of a fraction in which the numerator is the angle, and the denominator is the distance. The notes are given to the Topographer, and with the help of the elevations already obtained from the Leveller, he sketches in the contours. To facilitate this, he uses a table which gives the horizontal distance between two contours taken ten feet apart for each degree, as follows:

1°	is	573	per	10	feet	rise.
2°	"	286	"	"	"	"
3°	"	191	"	"	"	"
4°	"	143	"	"	"	"
5°	"	114	"	"	"	"
6°	"	95	"	"	"	"
7°	"	81	"	"	"	"
8°	"	71	"	"	"	"
9°	"	63	"	"	"	"
10°	"	57	"	"	"	"
11°	"	51	"	"	"	"
12°	"	47	"	"	"	"
13°	"	43	"	"	"	"

It is well for him to commit this table to memory.

He estimates distances beyond those measured by the Rodman, and so puts in distant hills, &c. For this it is convenient to have a pocket sextant. The Rodman runs out to different distances, according to the nature of the ground. If the country is level, he may run out 500 feet on each side of the centre-line, only doing so, perhaps, at intervals of 500 feet, or it may be necessary to run out that distance at every station. If the country is hilly, it may be sufficient to run out only 100 feet at each station.

A convenient form of clinometer is formed of a square board, with a string and bullet :

The more exact method is thus described in a private letter written by Mr. A. B. Nichols, in 1870, when he was Principal Assistant on the Bennett's Branch Extension of the Allegheny Valley Railroad :

"I always run experimental with the *vernier* as follows : Going ahead by myself, I select about the spot where I want to 'plug,' and let the Transitman take a sight on me, setting his vernier to the nearest quarter degree (except in special cases). I have the head Chainman carry a sight-staff, and set all the stakes with the transit. The head Chainman then sets the fore-sight plug when he arrives at the end of the sight. I use the needle merely as a check on the vernier. I think it better to set the

FORM OF TRANSIT NOTE BOOK.

'H.'

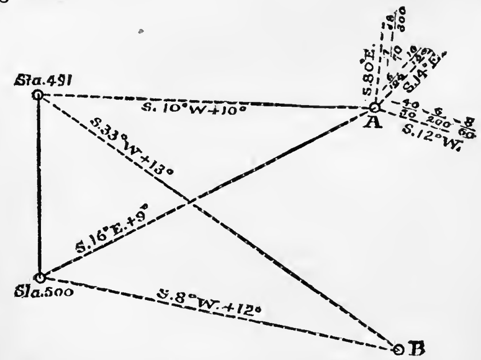
Sta.	Angle.	Deduced Course.	Needle.	Remarks.
8	....	....	....	+ 40 and + 73 edges of turnpike.
7	....	....	....	
6	....	....	....	+ 20 and + 55 stream.
5	L. 6°	N. 32¾° W.	N. 32¾° W.	
4	....	....	....	
3	....	....	....	
+ 30	R. 13°25′	N. 26¾° W.	N. 26¾° W.	
2	....	....	....	
1	....	....	....	
0	....	....	N. 40° W.	

stakes with the transit, as they are more reliable as references on location, and in an open country they can be set as fast as the Leveller can run (beyond which speed there is no use in running), while in a wooded section there is plenty of time to set them

while the Axemen are clearing. In thick woods, the Principal Assistant's voice has often to be taken as the guide ahead. The bench marks should be marked with the number of the station immediately preceding, and the distinctive letter of the line. Thus, if there happen to be a bench at 7 + 60 of 'H' line, it should be marked B. M. | 7 'H.'

"In regard to the Topographer's duties, I do not like the system of putting in the topography in the field. It has always been the custom, I believe, to run experimental one day and locate over the next. Mr. J. A. Wilson's method differs somewhat from this, and, I think, with reason. Topography put in in the haste that is inevitable in the field, is liable to many errors, and locations made on the previous day's experimental may not suit the country ahead. Mr. Wilson's method is to run all the necessary lines, take all the necessary notes, and then go into office quarters and work the maps up, and make a paper location which may then be run in and modified in the field.

"In 'Morrison's Cove' Mr. Linton took charge of the topographical department, taking the topography notes himself. His instruments were: a pocket compass, mounted on a light tripod, a Locke's level, and a small slope-board. His method of proceeding was as follows:



"Say that A is a tree on a hill, and B another point on another hill. He would set his compass up at 491, for instance, take the

courses to A and B, and measure the vertical angle with his slope-board. He would then proceed to A and take slopes in all directions, and in like manner from B, using his slope-board and level for heights and slopes. Then going to another station, as 500, he would fix the points A and B by other courses and slopes. Hollows can be shown by running a course up and taking slopes to right and left. By that means he could show the topography sometimes a half a mile from the line. I have known his elevations, say at A, to come within a foot of each other at the distance of half mile from the line, deduced from vertical angles taken with the slope-board, as from 491 and 500; seldom over two feet difference.

"The slope-board is a modification of the square-board and bullet. It will read to quarters of a degree, is furnished with sights,* and is used as follows:

"The Assistant Topographer takes his stand at the station, and gives the right angle to the line by means of a right-angle box, or otherwise. The Slope Rodman measures out the horizontal distance with a ten-feet-long pole to change of slope, and sights back on the man at the station, taking a point on the other's person (previously determined) at the same height above ground as his own eyes. He reads the slope, calls it and the distance out, and in the meanwhile the man at the station, be it the Assistant or the other Rodman, checks the slope by sighting on his person. Rodman No. 1 then measures ahead to the next change, while Rodman No. 2 comes up to *change* No. 1; they measure the slope, and so on. The Assistant keeps the books, and should be furnished with a 'Jacob's staff' and compass for taking buildings, and while so engaged the Rodmen can measure the sizes of said building with a tape, or can go on taking slopes, which they afterward report to the Assistant. Slopes should never be estimated, except one at the end of a series, and then it should be so marked, and the contours derived from it should be dotted on the map to avoid errors in location. In taking short slopes, one Rodman can take the right and the other the left of the line, thus facilitating matters."

From an inspection of the maps, it will be seen on which routes it is necessary to have paper locations made. A

* Mr. Linton's improved slope instrument may now be obtained at mathematical instrument makers.

paper location is such a line drawn upon the plan as may appear, taken in connection with the profile, to require the least excavation and embankment. The following is an excellent method of obtaining the cheapest location on the preliminary map: Having located a trial line by inspection, a profile is made, and grades assumed and drawn. A horizontal plane is supposed to pass through the point on the grade line at each station, and a point, in its line of intersection with the ground surface opposite the station, is marked with a red point. Having plotted these red points for a sufficient distance, they are connected by a line, which will resemble a contour line, and actually becomes one when the grade is level. The nearer the paper location can be drawn to this line, the less will be the excavation and embankment. If it coincides with it, the line will be a surface line.

Having made the locations on such lines as are considered desirable, a new profile is made from an inspection of where the located line cuts the contours, and cross-sections are plotted on a scale of ten feet to the inch, or on Trautwine's cross-section paper. From these cross-sections, the amounts of excavation and embankment are calculated, and the results embodied in a table of the following form:

Sta.	Distance.	Eleva.	Grade.	Cut.	Fill.	Areas.			Solids.		
						Excavation.		Embankment.	Rock.	Earth.	Emb.
						Rock.	Earth.				

The slopes of the cuts are sometimes assumed as follows:

When the slope of the ground is 20° or less, make the slope 1½ to 1.

When the slope of the ground is 20° to 35°, make the slope 1 to 1.

When the slope of the ground is over 35°, make a vertical wall.

Rock stands at ~~1~~¼ to 1.

Embankment is generally taken as sloping 1½ to 1.

From the calculated amount of excavation and excess of embankment, an estimate is made of the costs of different routes, and it is thus found which lines it will be necessary to actually locate in the field, in order to obtain a closer estimate, or for the purpose of constructing.

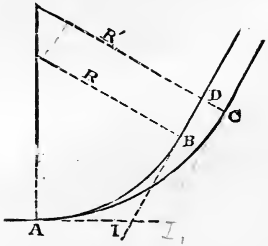
LOCATION.

The locating party is organized somewhat differently from the preliminary one. We have : Principal Assistant, Transitman, Leveller, Level-Rodman, Front Flagman, Back Flagman, two Chainmen, two or more Axemen.

The axeman who drives the stakes now carries tacks, or, better, lath nails, with him, and drives one in the plug at the point where the transitman is to set up. The transitman uses the vernier entirely, not using the needle, unless as a check on the tangents. The curves are all run on the ground, and the stakes which come upon them, set with the transit. The leveller keeps close up to the transitman, and constantly reports the heights to the Principal Assistant. The tangents are generally fixed by the paper locations, and the usual object is to run a given curve from one end of a tangent, and strike the hill with the point of tangent (*P. T.*) at a given elevation, viz., that on the paper location. Other problems will also often arise. The following are the most useful :

Problem 1. To change a curve so that it shall come out in a parallel tangent at a given distance from the old tangent, by

changing the radius. (From "Haslett & Hackley's Pocket-Book.")



To change the curve $A\,B$ so that it shall come out at C,

$$R' = R \pm \frac{D\,C}{1 - \cos.\ I}\,;$$

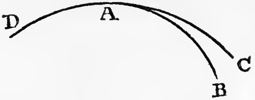
Correct.

or otherwise,

$$\text{Degree of curve } A\,C = \text{degree of curve } A\,B \mp \frac{8\,D\,C}{7\,n^2}$$

in which n is the number of 100-feet chords in $A\,B$.

Problem 2. To change the origin of a curve so that it may pass through a given point.



To move A, the point of compound curvature, so that the curve $A\,B$ will pass through the point C.

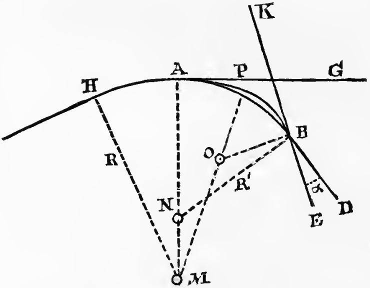
Take the distance $B\,C$, divide it by $A\,B$, and multiply by 57.3, * and we get the difference in deflection $C\,A\,B$, which, divided by the number of stations in $A\,B$, gives the difference in deflection per station (or look in the table of natural sines for $\frac{B\,C}{A\,B}$, from which is obtained the angle $C\,A\,B$, which is to be divided by the number of stations). Then take the difference between the degrees of the curves $A\,B$ and $D\,A$; then, the difference between the degrees of the curves is to the difference in deflection per

* 57.3 is the reciprocal of nat. sine of 1°

station as 100 is to the number of feet forward or backward we must go, on the curve $A\ D$, to strike the point C.

Problem 3. Having located a compound curve terminating in a tangent, it is required to change the point of compound curvature so that the curve will terminate in a tangent parallel to the located tangent, at any required distance perpendicular thereto. Divide the required distance between parallel tangents by the difference of radii of the two last branches of the curve. From the cosine of total amount of curvature in the last branch, subtract or add this quotient. The remainder, or sum, will be the natural cosine of the amount of curvature required for the last radius.

Problem 4. Having located a compound curve terminating in a given tangent, it is required to change the point of compound curvature, and also the length of the last radius, so as to pass through the same terminating point with a given difference in the direction of the tangent.



Having the curve $H\ A$ and the curve $A\ B$, with tangent $B\ D$, it is required to continue the first curve from A to such a point, P, that the tangent at B will have the direction $B\ E$.

Continue the curve $H\ A$ to the point P given by the following equation :

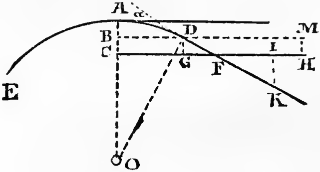
$$Cotan. \tfrac{1}{2}\, A\, M\, P = \frac{R}{R'}\,(cotan. \tfrac{1}{2}\, A\, N\, B + cotan. \tfrac{1}{2}\,\alpha) - cotan. \tfrac{1}{2}\,\alpha.$$

The curve from P to B is, of course, found by measuring the total deflection angle, and dividing by the number of stations.

We can, by means of this problem, connect two curves running toward each other with a third one. Let A and B be points on the respective curves. We wish to continue the curve $H\ A$ past A to some point, P, from which to run some third curve connecting with the other curve at B (the tangent $B\ E$ being common to the last two curves).

Measure the angle $G\ A\ B = \frac{1}{2}\ A\ N\ B$; also the angle $K\ B\ A = \frac{1}{2} A\ N\ B + \alpha$; and the distance $A\ B = 2\ R'\ sin.\ \frac{1}{2}\ A\ N B$. Then calculate $A\ M\ P$ from the above equation; dividing by the degree of the curve $H\ A$, gives the distance $A\ P$ in stations. From $\frac{1}{2}\ P\ O\ B = A\ N\ B + \alpha - A\ M\ P$ and the distance $P\ B$, we can find the degree of the curve $P\ B$.

Problem 5. To change the radius of a curve so that it will come out in a given tangent.



To change the radius of the curve $E\ D$ so that it will come out in the tangent $C\ H$.

Having run the curve until the tangent $D\ K$ is nearly parallel to $C\ H$, measure the offsets $D\ G$ and $I\ K$, and the distance $G\ I$. Calculate $G\ F$ and then $\alpha\ (= tan.^{-1} \frac{D\ G}{G\ F})$. We could also measure this angle directly by measuring off $M\ H = D\ G$ and taking a sight on M. Then $A\ C = A\ B + B\ C = R\ ver.\ sin.\ \alpha + D\ G$.

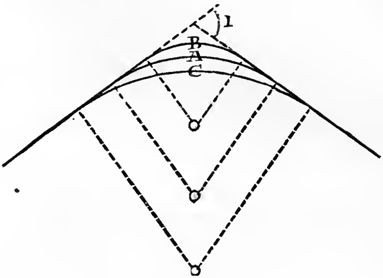
We then find the new radius by Problem 1.

$$R' = R \pm \frac{A\ C}{ver.\ sin.\ I}$$

(I = the former total angle minus α).

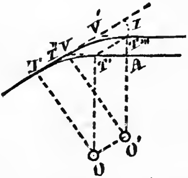
Problem 6. Having located a curve connecting two tangents,

it is required to move the middle of the curve any given distance either toward or from the vertex.



$$R' = R \pm \frac{A\,B \text{ or } A\,C}{\dfrac{1}{cos.\ \frac{1}{2}\,I} - 1}.$$

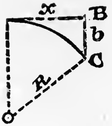
Problem 7. To change the origin of a curve so that it shall terminate in a tangent parallel to a given tangent at a given distance from it.



Let $T\,T'$ be the curve, $V\,A$ the given tangent, and $V'\,T'''$ the parallel tangent.

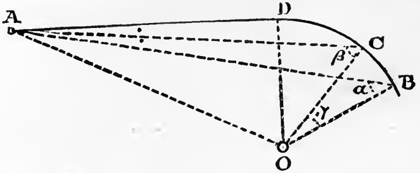
$$\text{Then } T\,T'' = \frac{A\ T'''}{sin.\ I.}$$

Problem 8. To find how far back it is necessary to go from the point B, to strike the point C with a curve of given radius ; $B\,C$ being known.



$$x = \sqrt{b\,(2\,R - b)}.$$

Problem 9. To draw a tangent to a curve from a point outside of it.

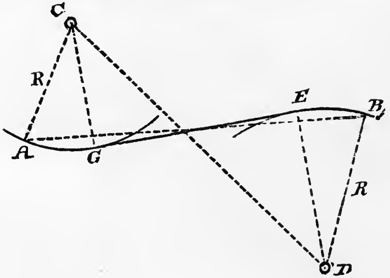


$$Sin.\ B\,A\,O = \frac{sin.\ (\gamma + \alpha - \beta)}{\sqrt{1 - 2\,\dfrac{sin.\ \beta}{sin.\ \alpha}\ cos.\ (\gamma + \alpha - \beta) + \dfrac{sin.^2\ \beta}{sin.^2\ \alpha}}}$$

$$sin.\ D\,A\,O = \frac{sin.\ B\,A\,O}{sin.\ \alpha}$$

$$D\,O\,C = 90^\circ + D\,A\,O - B\,A\,O - \gamma - \alpha.$$

Problem 10. To draw a tangent to two curves already located. 1st. When the curves are in opposite directions.



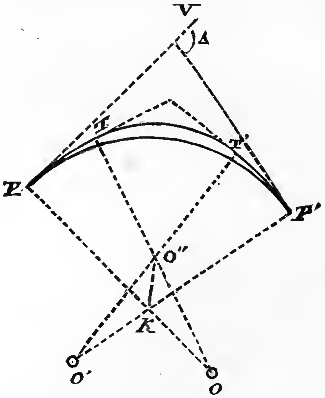
Stop both curves before getting to the tangent points. Observe $B\ A\ C$ and $A\ B\ D$, and measure $A\ B$. In the triangle $A\ B\ C$, calculate $C\ B$, $C\ B\ A$ and $A\ C\ B$; ($A\ C$, $A\ B$ and $C\ A\ B$ being known). In the triangle $B\ C\ D$ calculate $C\ D$, $B\ D\ C$ and $D\ C\ B$; ($B\ C$, $B\ D$ and $C\ B\ D = C\ B\ A + A\ B\ D$, being known).

$$Cos.\ E\ D\ C = \frac{R + R'}{C\ D.}$$

$$B\ D\ E = B\ D\ C - E\ D\ C$$
$$A\ C\ G = A\ C\ B - (E\ D\ C + D\ C\ B).$$

2d. When the curves are in the same direction. This is an extension of Problem 4.

Problem 11. To substitute a compound curve for a simple one. ("Henck's Pocket Book," p. 59.)

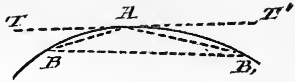


Let $P\ K = P'\ K = R$ and $P\ O = P'\ O' = R'$ and $T\ O'' = T'\ O'' = R''$ and $P\ O\ T = P'\ O'\ T' = 2\ \theta$ and $T\ O''\ T' = 2\ \theta'$. Assume R' and θ'.

Then $\Delta = 4\ \theta + 2\theta'$ and $O'\ O'' : K\ O' :: sin.\ O'\ K\ O'' : sin.\ K\ O''\ O'$, or $R' - R'' : R' - R :: sin.\ (\pi - \frac{1}{2}\ \Delta) : \theta'$.

$$\therefore\ R' - R'' = \frac{(R' - R)\ sin.\ \frac{1}{2}\ \Delta}{sin.\ \theta'.}$$

Problem 12. To locate the second branch of a compound curve from a station on the first branch.

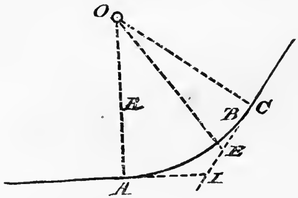


Let $A\,B$ be the first branch of a compound curve and D its deflection angle, and let it be required to locate the second branch $A\,B'$, whose deflection angle is D', from some station B on $A\,B$. Let n = the number of stations from A to B, and n' = number of stations from A to B'. Let $V = A\,B\,B'$; $(B\,A\,T = n\,D)$

$$V = \frac{n'\,(n\,D + n'\,D')}{n + n'}.$$

(See "Henck's Pocket Book," p. 61.)

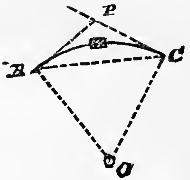
Problem 13. To locate a tangent from an inaccessible point on a curve.



Let C be the inaccessible point. Run the line to a point B.

$$B\,E = R\left(\frac{1}{\cos.\ C\,O\,B} - 1\right).$$
$$B\,E\,C = 90° - C\,O\,B.$$

Problem 14. To pass an obstacle on a curve.

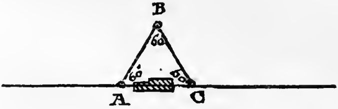


1st method. $A\,C = 2\,R\,sin.\ \frac{1}{2}\,A\,O\,C.$

2d " $A\,P = R\,tan.\ \frac{1}{2}\,A\,O\,C.$

$A\,O\,C$ must be assumed at such a value as, it is supposed, will carry the line beyond the obstacle.

Problem 15. To pass an obstacle on a tangent. ("Mifflin on Railway Curves," Prob. 17.)



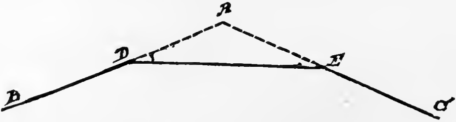
$$A\,C = A\,B = B\,C.$$

Problem 16. To find the distance across a river, in a preliminary survey. (Communicated by Mr. D. McN. Stauffer.)

From A put in the plug B on the opposite side in the line which is being run. Then turn off one degree and put in the plug C. Measure the distance $B\,C$; then

$$A\,B = \frac{100\,B\,C}{1.75} \text{ or } = 57.3\,B\,C.$$

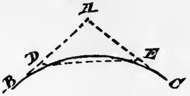
Problem 17. To find the radius of a circular arc which shall successively touch three straight lines $B\,D$, $D\,E$ and $E\,C$. (From "Rankine's Civil Engineering.")



$$\text{Radius} = \frac{D\,E}{tan.\ \frac{1}{2}\,D + tan.\ \frac{1}{2}\,E} \qquad (D = A\,D\,E \text{ and } E = A\,E\,D.)$$

Problem 18. To connect two tangents with a curve of a given

radius when the point of intersection is inaccessible. (From "Rankine's Civil Engineering.")



$$D\,A\,E = A\,D\,E + A\,E\,D - 180°.$$

$$A\,D = D\,E\,\frac{sin.\ A\,E\,D}{sin.\ D\,A\,E};\quad A\,E = D\,E\,\frac{sin.\ A\,D\,E}{sin.\ D\,A\,E}.$$

$$D\,B = R\ cotan. \frac{D\,A\,E}{2} - A\,D;\ E\,C = R\,cotan. \frac{D\,A\,E}{2} - A\,E.$$

The transit points (marked *Tr. P.*) are called "plugs," and consist of stakes driven flush with the ground. They are guarded by a stake set on one side with the number turned toward the plug, and under it written (say) "3′ off." All the other stakes should have their numbers turned toward the beginning of the line.

The following is the form of field-book: (From Shunk.)

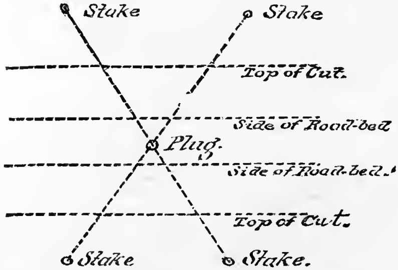
Station....	Distance....	Deflection...	Index.......	Tangent....	Course......	Mag. Course.	Remarks...
23 o	100	......	....	......	N. 20°00′ W.	N. 20°05′W.	At sta. 24 + 50 commence a 4° curve to the L. for 35°12′.
24	50	......	....	......	....	....	
P. C. + 50 o	50	1°00′	1°00′	......	....	....	
25	100	2°00′	3°00′	......	....	....	
26	100	2°00′	5°00′	......	....	....	
27	100	2°00′	7°00′	......	....	....	
28 o	100	2°00′	16°00′	14°00′	....	N. 34°07′W.	
29	100	2°00′	18°00′	......	....	....	

The final location having been made, the line is divided up into lengths of about one mile each, called sections, and a board placed on end at the dividing station, with the numbers of the sections on the sides. An estimate is

made of the amount of earth-work and masonry on each section, and the road is advertised for contract. The contractors are each furnished with a printed copy of the quantities in each section, and allowed to take such notes as they require from the map and profile, and walk over the ground, the section boards guiding them to the different work.

CONSTRUCTION.

The road is divided up into lengths of about thirty miles, each of which is placed in charge of a "Principal Assistant Engineer." Each of these divisions is subdivided into lengths of about seven miles, and given in charge of an Assistant Engineer, whose party consists of a Rodman, Chainman and Axeman. The first work of the Assistant should be to retrace the line and test the bench marks. All plugs should be guarded, and a bench should be made at every culvert. There are various modes of guarding plugs—by intersecting lines, by distances from other plugs, or a combination of the two. The best method, where the ground admits of it, is by intersecting lines.

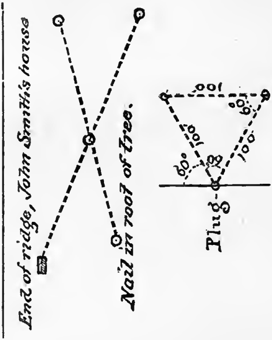


A part of a house, or the corner of a window or chim-

ney, may often be substituted for one of the above stakes, for a foresight.

The note book may be kept in the following form:

TOPOGRAPHY.



Station	Plug	Distance	Deflection	Reading	Total Angle	Remarks
87	P. T.	86 + 92	55′	8°35′	11°30′	Straight.
86			1°00′	7°40′		
85			1°00′	6°40′		
84	Tr. P.	84	1°00′	2°50′	5°40′	
83			1°00′	1°50′		
82			0°50′	0°50′		
81	P. C.	81 + 17				2° curve.

The advantage of this form of field book is, that having

first made and checked it in the office, there will be no more calculating of curves in the field, and so much less risk of error. It would always be necessary to run from the same end of the curve, and to use the same transit points; but this is no objection, as the plugs are all guarded, and it is as easy to set over one as another. Guarding all the plugs saves a great deal of trouble in re-running the line after grading, when it never measures the same as before, and it is difficult to run the old line without the *same* points to run from.

At the end of the transit note-book, a page should be devoted to each culvert, giving its station and a little plot of the stakes set, of course drawn roughly; and a little drawing of the culvert; also the level of the bridge seat and foundations, etc.

The staking out for excavation is done in several ways. In a tolerably flat or undulating country, it is generally done with the level; on steep hillsides, two rods are used, one ten feet long, and the other of any convenient length, divided into feet by different colors. That which is ten feet long is held horizontally by means of a hand-level laid upon it, with one end resting upon the ground, and the other against the shorter rod, which is held vertically. It is raised until it is horizontal, and the height read off the vertical rod by the Rodman, and noted by the Assistant on a piece of loose paper. He calculates where the slope runs out, and, having checked it on the ground, or made a closer approximation, enters it in a special field-book. The same principle governs the setting of the slope-stakes with the level and level-rod. As a large part of the Assistant Engineer's work consists in setting slope-stakes, a more minute description is perhaps necessary. They are set opposite the centre line stakes, at the tops of the cuts and bottoms
1½ of the fills. If the slope is 1½ to 1 and the half width of the road-bed is called b, the horizontal distance of the

slope-stake from the centre line is called x, and the height of the slope-stake above the sub-grade is called h; then

$$x = b + 1\tfrac{1}{2}h.$$

By assuming a value of x, measuring it out, and finding the corresponding value of h, with the level or the two rods, the values are substituted in the above equation; if both sides are the same, the assumed value of x was correct, and the stake should be driven in. If, however, the left-hand side is greater or less than the right-hand, the position of the stake should be moved toward or away from the centre line an estimated amount, and the process repeated of taking a new height with the level, and making a new calculation, until the two sides agree. After a little practice, it will not, usually, be necessary to make more than two trials. The following is the form of field book used:

Station...	Distance.	Ground...	Grade...	Cut......	Fill......	L. D......	L. C......	R. C......	R. D....

The "L. D." signifies the distance out and the height of the ground where the cut or fill strikes the surface of the ground on the left-hand side, while "L. C." means the cutting or filling at the half width of the road-bed on the same side. Some engineers look upon the calculation of the point where the slope runs out, in the field, as a waste of time; and only take the transverse slope, being sure to take it far enough out. They then plot the cross-section, and take the distance to the slope-stake from the plot with

a scale. They claim that this method is advantageous, too, because they always run out further than necessary for the slope, and if, afterward, as often happens, the slope will not stand, but slides out—a "slip"—they still have a record of the amount which slides by measuring to the top of the slide, while, too often, when such an accident occurs, the Assistant finds that he has no note of the slope of the ground beyond his stake, which has been carried away. When such an event occurs, it is better not to slope the cut further up, but to take away the earth at the level of the road-bed for some distance in, to catch any further slide before reaching the track, although the slope may be steeper than was intended.

In staking out with the level, it is well to have a number of sheets of paper, fastened together at the edges, for making trial calculations on; when one is covered with figures, it can be torn off and thrown away, exposing another. The cross-sections should be plotted in a permanent record book, to be kept in the office. The area of each should be calculated. For applying the prismoidal formula for calculating the cubic contents, it is requisite to know the middle cross-section between each two that are measured on the ground. The closest approximation to this is the following: Each cross-section is supposed to be transformed into another of equal area, but with a horizontal ground surface, and the depth at the centre of this new cross-section calculated. The depth of the middle section required, is supposed to be equal to the mean of the two end "equivalent centre depths." From this depth the area of the middle section is obtained and substituted in the formula:

$$S = \frac{l}{6}(A + 4\,M + A'),$$

where A and A' are end areas, and M is the middle area, and l is the distance of end stations apart. Tables have

been constructed of "equivalent centre depths" for various areas, and other tables give the cubic contents at once, for a given length and given slopes, from the equivalent centre depths of the end sections.

At the top of cuts it is well to have a ditch made on the up-hill side to keep the slope from being washed down. Proper dimensions are :

It should be placed about three feet from the edge of the slope.

Estimates of the work done are taken up each month. It is important that all papers containing notes of the measurements should be preserved. Although these estimates are only intended as rough approximations, the measurements taken will often prove of service in following estimates.

CULVERTS.

For finding the proper water-way to give to culverts, the drainage area of the stream should be discovered if possible. Where county maps are obtainable, this can easily be measured from them. If the drainage area is small, it may often be estimated by walking round it. The water-way may then be calculated by the following formula of Mr. E. T. D. Myers :

$$A = c\sqrt{M},$$

in which A is the area of the opening of the culvert in square feet, M is the drainage area in acres, and c is a variable co-efficient, depending on the country, and for which Mr. Myers recommends $1\frac{6}{10}$ in hilly, compact ground,

and 1 in comparatively flat ground. In mountainous, rocky country, this value may often be raised to 4. Inquiry should be made of the neighboring people to learn the greatest height of floods in the stream, and the vertical dimension of the water-way may be made equal to the flood height of the stream at the spot.

BOX CULVERTS.

Rule for laying out on the ground: Take the height of the top of the parapet from the height of the embankment at the centre, and with the remainder (considered as height of embankment) find the side distances with the level as in setting slope-stakes; then add 18 inches at each end, and if the height of the embankment exceeds 10 feet, add one inch on each end for every foot in height above the parapet.

The covering flags are one foot thick and the parapet one foot high, making two feet from top of abutments to top of parapet. For the thickness of abutments, take $\frac{1}{5}$ the height of embankment on top of abutments, observing, however, that the abutments must never be less than two feet nor more than four feet thick. To determine the length of the wings, add the height of the opening to the thickness of the flags; one and a half times this sum, added to two feet, will give the distance from the end of opening to end of wing; the wing to be at right-angles to the drain, unless the latter be askew; then the wings to be parallel to the direction of the railroad. Instead of digging deep foundations, the method now employed is to put in a paving made of stones a foot deep, set up on edge, with a curb two feet deep at each face of the drain, and to start the walls on this paving. Should the fall of the drain not exceed 9 inches, make the pavement level, dropping the upper end 9 inches below the surface. Should the fall be greater, make a suffi-

cient number of drops of 9 inches each in the length of the drain. At every drop place a cross-sill 2 feet deep ; the wings and parapet to be of the same thickness as the abutments. The above rule was adopted on the construction of the Junction Railroad of Philadelphia.

Box culverts are not usually made of a greater span than three feet. If more water-way is required, two openings are placed, each three feet wide, with a wall separating them, two feet thick.

OPEN CULVERTS.

These are generally made of two feet span, with walls two feet thick, with a depth of not more than three feet, founded on a paving, one foot thick.

CATTLE GUARDS.

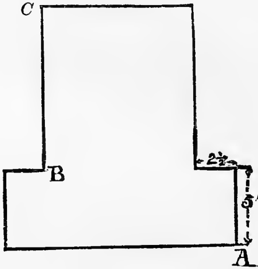
These are often placed on each side of a public road crossing, when this takes place at grade. They are built like open culverts with spans varying from three to five feet, and about three feet deep. Stringers $12'' \times 12''$ placed 3 feet 11 inches in the clear, support the rails, of a sufficient length to rest 5 feet on the solid wall and ground on each side. Two struts, $5'' \times 12''$, and 4 feet 6 inches long, and mortised into each stringer $3\frac{1}{2}$ inches, are placed about six inches further apart than the span of the opening, and the stringers are held to them by a rod one inch diameter, 6 feet 5 inches long, with square nuts and long flat washers, placed by each strut.

OPEN PASSAGE-WAYS.

These are made either with wing-walls or "T" abutments. When with wing-walls, the thickness at the base should be calculated like a retaining wall ($\frac{3}{7}$ the

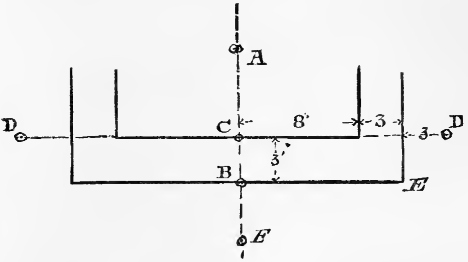
height). The wing-walls are usually placed at an angle of 45° with the centre line, that angle requiring least masonry. The coping then slopes down at the rate of 2.12 to 1, which is a good proportion for steps, if they are preferred. If the road is for a single track, the "T" abutment will be found more economical. The length of the "T" should be so calculated that the earth sloping down it at the rate of $1\frac{1}{2}$ to 1, and striking the back of the bridge-seat, and then one end, should just strike the ground at the corner of the bridge-seat, or as near it as the Engineer desires. For instance, suppose the distance from A to sub-grade is 12 feet; then

$$12 \times 1\frac{1}{2} = 5 + 2\frac{1}{2} + x, \text{ or } x = 10\frac{1}{2} = \text{length of } BC.$$



In staking out for a passage-way, always make the pit a foot larger all round than the foundation is intended to be, so that the quality of the masonry can be seen. The mason would prefer to fill up the entire pit. If the passage-way is on a curve, having decided where one face should come, turn off from the nearest plug the angle corresponding to the sub-chord at the face, and put in a plug; set up over this, and turn off the sub-chord to the face of the other abutment. Turn off right-angles from this last sub-chord at each of these plugs, and put in others outside of the

pits for the mason to stretch his line by, for the faces of the abutments. Plugs should also be put on both sides of the last sub-chord produced, beyond the pits, to give the centre line of the bridge. This finishes the instrumental work, the other stakes being put in with a tape. A convenient way of doing this is as follows :



Let $A\ F$ be the centre line, marked with plugs at A and C, and let $C\ D$ be the face of the neat work. A stake is to be put in at the corner of the pit E, the pit being supposed to be 3 feet larger all round than the neat work. Lining by eye, put in a stake B 3 feet from C. Then, with the ring of the tape at B and the 17-feet mark at D, take hold of the 14-feet mark and draw the tape tight ; the 11-feet mark will give the point E.

It is well to give the mason a sketch on a piece of paper, giving all dimensions, drawn on the spot by eye without scale, and let him do his own marking out on the foundation. The pit is a sufficient guide for putting in the foundation. After setting the stakes for the pit, take levels on each one and note in the book ; also note the depth of the pit before the masonry is begun, so that the cubic contents can be calculated. A level has also to be taken at the face before laying out the neat work, to give the height of the

neat work to bridge-seat and for calculating the batter and span at the bottom. A 12-feet span bridge, 12 feet high, with a batter of one-half an inch to the foot, would be only 11 feet span at the base of the neat work.

STONE ARCHES.

Rankine's rule for the depth of the keystone in feet:

For a single arch, $D = \sqrt{.12\,R},$

For an arch in a series, $D = \sqrt{.17\,R},$

in which R is the radius at the crown in feet.

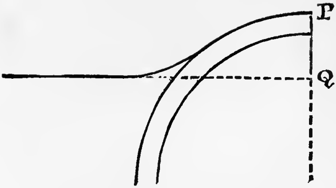
This is for circular or segmental arches. For elliptical arches, for R substitute $\frac{a^2}{b}$ when the earth is dry, or $\frac{4a^2}{b}$ when the earth is wet, a being the half-span, and b being the rise.

Trautwine's rule is:

$$D = \frac{\sqrt{R + \frac{1}{2} S}}{4} + .2 \text{ foot},$$

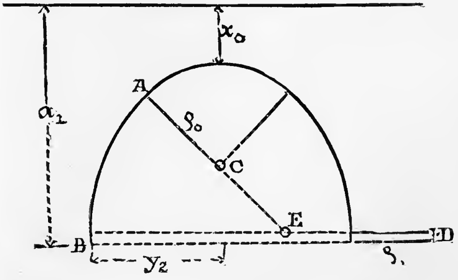
in which R is the radius of the circle which will touch the crown and the springing lines, and S is the span.

Rankine gives. as the thickness of the abutment from $\frac{1}{3}$ to $\frac{1}{5}$ of the radius at the crown (for abutment piers, $\frac{1}{2}$ the radius), and for the thickness of the piers $\frac{1}{6}$ to $\frac{1}{7}$ of the span. He says to make the masonry of the pier solid up to the point where a line from the centre of the arch to the extrados forms an angle of 45° with the vertical. Fill in the backing before striking the centres to such a height that $P\,Q = \sqrt{r'r - r^2}$ where r is the radius of the intrados, and r' is the radius of the extrados.



Trautwine gives for the thickness of the abutment at the springing line, when the height above the ground of this line is not more than $1\frac{1}{2}$ times the base, $= \dfrac{\textit{Rad. in ft.}}{5} + \dfrac{\textit{rise in ft.}}{10} + 2$ feet. (See his "Pocket Book" for finding the thickness at the base.)

If the embankment over the arch is very high, or if the arch is the lining to a tunnel in earth, the proper form for the intrados is a geostatic arch. Rankine's approximate formula for this is :



$$y_2 = \tfrac{1}{2}(x_1 - x_0)\sqrt[3]{\frac{x_1}{x_0}}\left\{1 - \frac{1}{30}\sqrt[3]{\frac{x_1}{x_0}}\right\}.$$

In any given case x_1 and y_2 will be known, and we can

calculate x_0 by trial. $x_1 - x_0$ will then be the rise of the arch which we shall call a. The geostatic arch will approach a five-centre curve which may be drawn as follows :

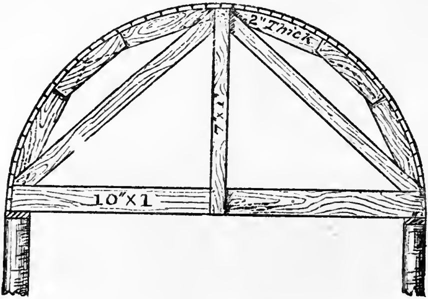
$$\text{Calculate } b = \tfrac{1}{2}\, y_2 + \frac{\tfrac{1}{4}\, y_2{}^2}{30\, a}.$$

$$\text{Then } \varsigma_0 = A\,C = \frac{a}{2}\left(1 + \frac{b^3}{a^3}\right) \text{ and } \varsigma_1 = B\,D = \frac{a}{2}\left(1 + \frac{a^3}{b^3}\right).$$

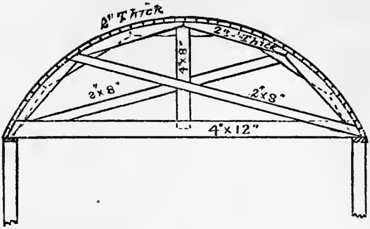
From these equations we obtain the centres C and D. About D with a radius $D\,E = \varsigma_1 - a$ describe a circular arc, and about C with a radius $C\,E = a - \varsigma_0$ describe another arc ; the intersection of these at E will be the third centre.

When brick is plentiful, circular culverts are often employed. They require no foundation except for the face walls. For the thickness, one brick (nine inches), is sufficient for a span less than six feet. Add one more brick for each six feet more of span up to thirty feet.

The following are two cheap forms of centring :



14-feet span. Frames 2½ feet apart.



24-feet span, 8-feet rise. Frames 3½ feet apart.

Post mortised (by slight tenon) into chord. Arch pieces pinned together and halved in chord and post; braces spiked at ends; and at intersection with post a ½-inch bolt is used.

Centres should be removed from arches, unless laid in a very quick-setting mortar, within a few days after their completion. In stone arches the parapet should not be made too high, or it may be pushed over by the bank; it is well to proportion it like a retaining wall if more than one or two courses high. Some loose stones laid flatwise behind it will relieve the thrust of the earth.

In designing centres, allow $\frac{1}{300}$ of the span for settling of the arch, unless built very slowly and with great care.

RETAINING WALLS.

Let b = the breadth at the bottom = 1.
" h = the height.
" t = the thickness at the bottom.
" w = the weight of a unit of volume of masonry.
" w' = the weight of a unit of volume of earth.
" θ = the slope of the bank above the wall.
" φ = the angle of repose of earth.

Let j = the inclination of the foundation pit to the horizon.
" q = a constant of safety

$$= \frac{\text{distance from middle of base to point where the line of resistance cuts base}}{t}$$

It is always between 0 and ½.

Let q'

$$= \frac{\text{distance from the middle point of base to point where base is cut by a vertical line through the centre of gravity}}{\text{thickness at base.}}$$

It is always less than $\frac{1}{6}$.

$$\text{Let } n = \frac{\text{total weight of masonry}}{w\,h\,b\,t.}$$

$$\text{Let } w_1 = w' \cos.\,\theta \,\frac{\cos.\,\theta - \sqrt{\cos.^2\,\theta - \cos.^2\,\varphi}}{\cos.\,\theta + \sqrt{\cos.^2\,\theta - \cos.^2\,\varphi}.}$$

Rankine then gives :

$$\frac{t}{h} = \sqrt{\frac{w_1 \cos.\,\theta}{6\,n\,(q \pm q')\,w \cos.^2 j} + \left(\frac{w'\,(q + \frac{1}{2})\sin.\,(\theta + j)}{4\,n\,(q \pm q')\,w \cos.^2 j}\right)^2}$$
$$- \frac{w'\,(q + \frac{1}{2})\sin.\,(\theta + j)}{4\,n\,(q \pm q')\,w\,\cos.^2 j.}$$

$$\text{If } \theta = 0\,;\; w_1 = w' \frac{1 - \sin.\,\varphi}{1 + \sin.\,\varphi.}$$

If $\varphi = 35°$; $w_1 = .27\,w'$.

If $n = \frac{1}{2}$ and $j = 0$ in addition,

$$\frac{t}{h} = \sqrt{\frac{.27\,w_1}{3\,(q \pm q')\,w.}}$$

If we suppose the wall to be just stable without the least excess of strength, $q = \frac{1}{2}$. It is customary, however, to give q a smaller value, so that there will be an excess of strength ; otherwise the pressure would be concentrated at a point, and it would split off or crush. The English engineers make $q = .375$.

For q' we can assume the following values for walls of different heights:

Height of wall.	q'
20	.11
35	.14
55	.14
100	.16

For first-class masonry we may take $\dfrac{w'}{w} = \dfrac{100}{165}$

For dry sand-stone rubble we may take " $= \dfrac{100}{120}$

Then if the wall is over 100 feet high, of first-class masonry, $\dfrac{t}{h} = .51$

"	"	"	"	dry rubble	"	"	.60
"	" between 55 & 100 ft. high, first-class				"	"	.49
"	"	"	"	dry rubble	"	"	.58
If the wall is between 35 & 55 ft. high, of first-class					"	"	.48
"	"	"	"	" dry rubble	"	"	.56
"	" less than 20		"	first-class	"	"	.45
"	"	"	"	" dry rubble	"	"	.53

When the wall is rectangular in section:

If of first-class masonry, $\dfrac{t}{h} = .27$

" dry rubble " " .32

When $\theta = \varphi$, all the previous values of $\dfrac{t}{h}$ become ~~less~~, ac- mor
cording to Rankine's formula. Mr. Trautwine, however, says they should be greater, and he has experimented with models under the different conditions.

The following are the rules used by different authorities:

In a discussion before the American Society of Civil Engineers ("Transactions," vol. 3, p. 75), a Canadian engineer was quoted as giving $\dfrac{t}{h} = \frac{2}{5}$ for first-class masonry laid in

hydraulic cement. A rule used on the Pennsylvania Railroad is $\frac{t}{h} = \frac{3}{7}$. Rankine gives, as the ordinary English rule, $\frac{t}{h} = .41$, and for a very safe rule $\frac{t}{h} = .48$.

Trautwine gives:

For rectangular walls of first-class masonry,	$\frac{t}{h}$	=	.35
and of mortar rubble or brick	"	"	.40
and of dry rubble	"	"	.50

When the walls are offset at the back, he recommends a thickness at the base of about $\frac{1}{8}$ more, and at the top of $\frac{1}{2}$ less, containing the same amount of masonry. (See his book.)

It was the practice on the Pennsylvania Railroad to make the base $\frac{3}{7}$ of the height, and after carrying the back plumb for three or four feet, to make a step, calculating the new thickness of wall at $\frac{3}{7}$ of the remaining height, and so continuing to step off to the top, where a thickness of three feet was given.

In railroads along a river bank, where the embankment slopes into the river, the slopes are "pitched" with stone about two feet long, laid upon the slope, at right-angles to it. They should start at the bottom in a trench dug about three feet below the surface of the ground.

TUNNELS.

A "heading" is first driven. This is about five or six feet high, and as wide as the nature of the material will allow. In earth it may only be three feet, while in solid rock it should be of the full width of the tunnel. In earth, it is generally driven at the bottom of the section of the tunnel; in this case chambers are often excavated of the

full size at intervals in the heading, and the work prosecuted from each in both directions until they meet. In solid rock, the heading should be at the top of the section of the tunnel, and the enlargement should be carried on as closely to the heading as possible, say within fifty feet, although where machine-drills are used, it may not be possible to keep so close.

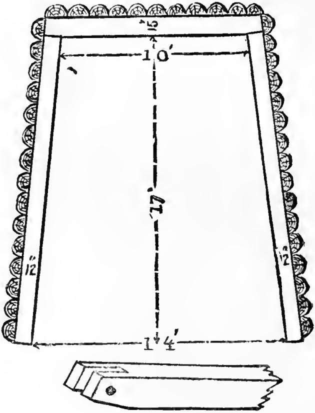
When the two ends of the tunnel are so near the same level that the difference in their heights is not sufficient to secure a proper fall for drainage, a summit should be made in the tunnel. On the Mont Cenis tunnel a fall of .05 per 100 was considered sufficient, but Mr. B. H. Latrobe recommended .5 per 100. The St. Gothard has .1 per 100; Musconetcong, .15 per 100.

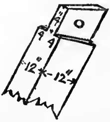
When shafts are sunk for the purpose of accelerating the work by having so many additional faces to work from, they should be filled up on the completion of the tunnel, as they interfere with the ventilation. It is found that the ventilation of the Hoosac tunnel is very bad since completion. It has a shaft in the middle which is left open, and acts well in removing the smoke from one end, but not from the other; the clear end depending, it is believed, on the direction of the wind.

When the tunnel is through earth or rotten rock, it will require to be arched. This is done with either brick or stone; in the London clay, which swells on being exposed to the air, it required a thickness of 54 inches of brickwork to withstand the pressure; 18 inches to two feet is the ordinary thickness. The Metropolitan Railroad, in London, goes under warehouses eighty feet high with a thickness of fourteen bricks, laid in cement, with a layer of concrete on top.

The proper form for the intrados of a tunnel through sand, or some such substance which acts only by its weight,

is the geostatic arch, to which a near approximation is made, when the load is infinite, in an ellipse with the semi-vertical axis double the semi-horizontal, or the rise equal to the span. In substances like the London clay, however, which swell on exposure to the air, a circular form is probably the best for the intrados. In soft material, the heading and the enlargement have to be timbered as they advance. The following was the method adopted on the Northwestern Virginia Railroad:





Legs squared 12″ and 17½′ long. Cap, 12 feet long, 15 ×

12 inches. Lagging half round, split out, about six inches thick, long enough to lie on two bents. After it was put in, the earth was rammed into the intervening space.

For the timbering on the Central Pacific Railroad, a longitudinal sill on each side, 12″ × 12″, carried the posts, 12″ × 16″, inclining outward at top, at intervals of 1½ to 5 feet. On these posts arches were made (polygons of seven sides) of three thicknesses of 5″ × 12″ plank, bolted with ¾ inch bolts. Width of sub-grade inside posts was 17 feet, and at springing line 19 feet. Height of crown above grade, 19 feet 9 inches. Split lagging on top, 2½ inches thick.

The timbering should be put in large enough for the masonry to be built inside; the earth is then tamped in above, the timbering sometimes remaining in, although it had better be taken out. For running the line in rock tunnels, the transit points are made in the heading by driving wooden plugs in the roof, and centring them.

The excavation for the St. Gothard tunnel is 8 meters wide by 6 meters high, exclusive of space for the masonry. The heading was 2.4 meters high and 2.6 meters wide, kept about 200 or 250 meters ahead of the enlargement, at the top of the enlarged section. The enlargement is first made by cutting the place for the roof. About 200 or 250 meters further back, a cutting is made about 3 meters wide, down to the floor of the tunnel. About the same distance still further back, the whole section is excavated, and the remaining masonry put in. The heading of the Clifton tunnel was 8 × 10 feet.

In the heading for a tunnel on the Great Western and Midland Railroads, at Bristol, thirty to forty shots were required to bring away the face, the holes being three feet six inches deep. They were exploded successively, beginning with the central holes, which were angled, and progressing

to the outside ones. At the Mont Cenis, the machines were too long to allow of putting the first holes at an angle, and the first opening was made by putting down larger holes in the centre, which were not fired.

In the Musconetcong tunnel, a slope was made, instead of a shaft, 8×20 feet in the clear, at an angle of 30 degrees. Through earth it was timbered with collars of 12×12 inches oak, 4 feet apart, centre to centre, supported by end and two middle props, lagged at the sides and above with chestnut "forepoling." Through rock the dimensions were 8×16 feet. Top headings were started in the tunnel 8×26 feet wide. Where the rock was disintegrated, collars of 15 inches oak, set 5 feet apart, were used, lagged above and sometimes at the sides, and supported either on legs or by hitches in the rock. These collars were sufficiently high to clear a two-foot ring of masonry, and about them packing was securely blocked in, up to the roof. The heading at the end of the tunnel was made 26 feet wide by 7 feet high. A heading through earth was made 8 feet at top and 10 feet at bottom, and 8 feet high, with oak collars and props of 12 to 15 inches round timber; sets placed 2½ to 2 feet apart, centre to centre, footed in very soft ground on six-inch sills, but ordinarily on three-inch foot-blocks. This information is obtained from Mr. Drinker's "Tunneling," p. 221.

BRIDGES.

Simple beam uniformly loaded, rectangular:

Let $W =$ the breaking weight in pounds.
" $b =$ the breadth of the beam in inches.
" $d =$ the depth of the beam in inches.
" $L =$ the length of the beam in inches.
" $S =$ a constant which has been determined by experiment.

The value of S is, for oak, 10,000; for white pine, 7,000; for wrought iron, 40,000; for cast iron, 30,000.

$$W = \frac{4}{3} S \frac{b\,d^2}{L.}$$

Beam uniformly loaded, cylindrical:

Let r = the radius in inches, the other letters being as before.

$$W = \frac{4\,S}{L} 3.1416\,r.$$

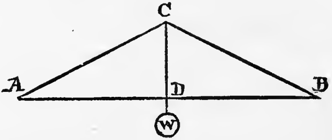
Beam uniformly loaded, I-shaped section:

If the flanges are of the same size, as they always are in rolled beams:

Let d = the depth of one of the flanges.
" d' = the depth of the connecting piece.
" A = the area of one of the flanges.
" A' = the area of the connecting piece.

$$W = \frac{4\,S}{3\,L} \left\{ 4\,(d + d')\,A + \frac{d'^2\,(A + A')}{d' + 2\,d} \right\}.$$

When the load is supported in the middle, instead of being uniformly distributed, the breaking load in each of the foregoing cases becomes only half as much.



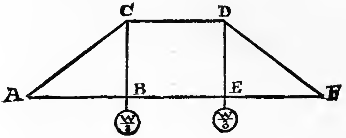
The king-post truss:

Strain on $C\,D = W$; strain on $A\,C$ and $C\,B = \frac{W}{2} \frac{A\,C}{C\,D.}$

Strain on $A\,B = \frac{W}{2} \frac{A\,D}{C\,D.}$

If the load is uniformly distributed, it will produce the

same effect as one-half the above load suspended in the middle. The beam is supposed to have no stiffness at D. Actually, $A\ B$ is always made in one stick, and its stiffness will reduce the above values by an indeterminate amount.



The queen-post truss :

$A\,B = B\,E = E\,F.$

Strain on $C\ B$ and $D\,E = \frac{1}{3}\ W.$

Strain on $A\ C$ and $D\,F = \frac{1}{3}\ W \times \dfrac{A\ C}{C\,B.}$

Strain on $C\,D = \frac{1}{3}\ W \times \dfrac{A\ B}{C\ B} =$ strain on $A\ F.$

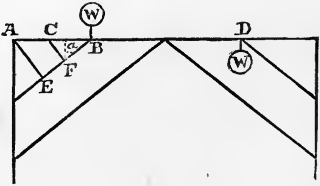
These are the strains when loads of $\frac{1}{3}\ W$ are placed at B and E, or a total uniform load of W. In the latter case, the abutment at A has to sustain, in addition, the load on $\frac{1}{2}\ A\ B$, which, added to the resolved component of the strain on $A\ C$, produces a vertical strain of $\frac{1}{2}\ W$, as it ought.

If only the point B is loaded with $\frac{1}{3}\ W$, the strains on $A\ C$, $C\ D$ and $A\ E$ are the same as before ; but there is an upward strain on $D\ E$ equal to $\frac{1}{3}\ W$, which must be resisted by the transverse strength of the beam $B\ F$, calculated in the same way as the first case of the simple beam loaded in the middle (of a length $B\ F$, not $A\ F$). If

braces are introduced in the directions $B\ D$ and $C\ E$, the bridge becomes a Howe truss.

Strains are the same in this case as in the king-post truss, the tension on the straining beam, however, being converted into thrust against the abutments.

Strains are the same as in the queen-post truss.

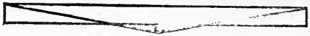


This is a combination of the king and queen post systems.

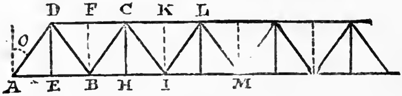
To prevent the point B from rising on the application of a weight at D, braces are often introduced at $A\ E$ and $C\ F$. The force W, acting upward at B, produces a force equal to $W \sin. \alpha$ in the direction of $C\ F$ ($C\ F$ being at right angles to $F\ B$) and acting at B, which has a tendency to break the beam transversely at F. The formula

for the breaking weight of a beam fixed at one end and loaded at the other is $W = \frac{1}{6} S \frac{b\,d^2}{L.}$ The pressure on $C\,F$ is also $W \sin. \alpha$, which produces a transverse strain in $A\,B$ at C, which can be calculated in like manner.

The trussed girders of the following forms may be looked upon as king and queen post trusses inverted :



They are objectionable as being a combination of two systems, and it is impossible to tell just how much of the load will be borne by the beam acting as such, or by the rods transmitting a portion of the strain to compress the beam. It depends on the adjustment of the rods.



The "Warren girder," or "triangular truss:"

Let W = the weight on one panel = the weight on $F\,C$ due to uniform load or weight of bridge.

" W' = the weight on one panel = the weight on $F\,C$ due to the variable load.

" n = the number of panels $A\,E$, $E\,B$, etc.

If the load is on the upper chord, struts $F\,B$, $K\,I$, etc., are introduced, and if on the lower chord, rods $D\,E$, $C\,H$, etc., so that each apex of the triangles will bear a load. The maximum strain on one of these struts or ties would be $W + W'$.

The maximum compression on $A\,D = \frac{n-1}{2}\,(W + W')\ sec.\ \theta.$

The maximum compression on $D\,B = \frac{1 \times 2}{2 \times n}\ W'\ sec.\ \theta.$ (see errata

The maximum tension on $D\,B$

$$= \left\{(n-2)(n-1)-2\right\}\frac{W\ sec.\ \theta}{2\,n} + \left(\frac{n-2}{2} \times \frac{n-1}{n}\right) W'\ sec.\ \theta.$$

The maximum compression on $B\,C$

$$= \left\{(n-3)(n-2)-(2 \times 3)\right\}\frac{W\ sec.\ \theta}{2\,n} + \frac{(n-3)(n-2)}{2\,n}\ W'\ sec.\ \theta.$$

The maximum tension on $B\,C = \frac{2 \times 3}{2\,n}\ W'\ sec.\ \theta.$ (see errata)

The maximum compression on $C\,I = \frac{3 \times 4}{2\,n}\ W'\ sec.\ \theta.$ (" ")

The maximum tension on $C\,I$

$$= \left\{(n-4)(n-3)-(3 \times 4)\right\}\frac{W\ sec.\ \theta}{2\,n} + \frac{(n-4)(n-3)}{2\,n}\ W'\ sec.\ \theta.$$

The maximum compression on $I\,L$

$$= \left\{(n-5)(n-4)-(4 \times 5)\right\}\frac{W\ sec.\ \theta}{2\,n} + \frac{(n-5)(n-4)}{2\,n}\ W'\ sec.\ \theta.$$

The maximum tension on $I\,L = \frac{4 \times 5}{2\,n}\ W'\ sec.\ \theta,$ (see errata

etc., etc., to the middle of the bridge, when the order will be reversed.

The strains on the chords are greatest when the bridge is uniformly loaded. We then have:

Tension on $A\,B = \frac{n-1}{2}\,(W + W')\ tan.\ \theta.$

$$\text{Tension on } B\,I = \frac{n-1}{2}\,(W + W')\ tan.\ \theta$$
$$+ \left\{(n-2)(n-1)-2\right\}\frac{(W + W')\ tan.\ \theta.}{2\,n}$$
$$+ \left\{(n-3)(n-2)-(2 \times 3)\right\}\frac{(W + W')\ tan.\ \theta}{2\,n.}$$

Tension on $I\,M$ = tension on $B\,I + \Big[\Big\{ (n-4)\,(n-3) - (3 \times 4) \Big\}$
$+ \Big\{ (n-5)\,(n-4) - (4 \times 5) \Big\} \Big] \dfrac{(W + W')\,tan.\ \theta}{2\,n.}$ etc., etc.

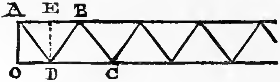
Compression on $D\,C$

$$= \left[\frac{n-1}{2} + \Big\{ (n-2)\,(n-1) - 2 \Big\} \right] \frac{(W + W')\,tan.\ \theta}{2\,n.}$$

Compression on $C\,L$ = compression on $D\,C$

$$+ \Big[\Big\{ (n-3)\,(n-2) - (2 \times 3) \Big\}$$
$$+ \Big\{ (n-4)\,(n-3) - (3 \times 4) \Big\} \Big] \frac{(W + W')\,tan.\ \theta}{2\,n,}$$

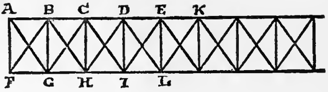
etc., etc. If the roadway is on the upper chord, the inclined piece, $A\,D$, in the last figure, is sometimes left out, and the bridge built as follows :



$A\,D$, $D\,B$, $D\,E$, etc., sustain the same amount of strain as before, but what was then compression is now tension, and *vice versa.* $A\,B$ has the same amount of strain as $A\,B$ in the other figure, and $D\;C$ as $D\;C$, the kinds being reversed as before. The part of the lower chord, $D\;O$, might, in this case, be dispensed with, were it not that it is of use in the lateral bracing, and must, therefore, be introduced.

The triangular truss is often built with two or more sets of different triangles forming the bracing; when of more than two, it is called a lattice truss. The strains on these can easily be represented in formulas as above, but are omitted for the sake of brevity. Each separate system of

triangles has strains like the previous form, but independent of each other.



The Howe truss :

Let n = the number of panels.
" W = the weight on one panel due to the uniform load.
" W' = the weight on one panel due to the variable load.

Maximum compression on $FB = \frac{n-1}{2}(W+W')\frac{FB}{BG}$.

Maximum compression on GC
$$= \left\{\frac{n-3}{2}W + \frac{(n-2)(n-1)}{2n}W'\right\}\frac{FB}{BG}.$$

Maximum compression on HD
$$= \left\{\frac{n-5}{2}W + \frac{(n-3)(n-2)}{2n}W'\right\}\frac{FB}{BG}.$$

Maximum compression on IE
$$= \left\{\frac{n-7}{2}W + \frac{(n-4)(n-3)}{2n}W'\right\}\frac{FB}{BG},$$

etc., etc. By continuing this process past the middle of the bridge, we obtain the maximum strains on the counter-braces, and when a strain becomes minus, it shows that beyond that point the counter-braces may be left out.

Maximum strain on BC
$$= \frac{n-1}{2}(W+W')\frac{FG}{BG}$$
= maximum strain on FG.

Maximum strain on CD
$$= \left\{\frac{(n-1)+(n-3)}{2}(W+W')\right\}\frac{FG}{BG}$$
= maximum strain on GH.

Maximum strain on DE
$$= \frac{(n-1)+(n-3)+(n-5)}{2}(W+W')\frac{FG}{BG}$$
= maximum strain on HI.

Maximum strain on $E\,K$

$$= \frac{(n-1)+(n-3)+(n-5)+(n-7)}{2}\,(W+W')\,\frac{F\,G}{B\,G}$$

$=$ maximum strain on $I\,L$.

These calculations should be stopped at the middle panel ; the other side will be the same.

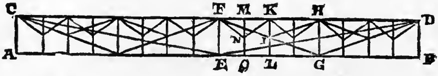
The maximum strain on $B\,G = \frac{n-1}{2}\,(W+W')$ for a through bridge, or W' less for a deck bridge.

The maximum strain on $C\,H = \frac{n-3}{2}\,W + \frac{(n-2)(n-1)}{2\,n}\,W'$ for a through bridge, or W' less for a deck bridge.

The maximum strain on $D\,I = \frac{n-5}{2}\,W + \frac{(n-3)(n-2)}{2\,n}\,W'$ for a through bridge, or W' less for a deck bridge.

The Pratt truss has the same outline as the Howe truss, but the verticals are struts, and the diagonals ties. The strains would be the same as those for the Howe truss, except that $F\,G$, $G\,H$, etc., should be changed to $A\,B$, $B\,C$, etc., and $F\,B$, $G\,C$, etc., to $A\,G$, $B\,H$, etc.

Both trusses are sometimes made "double intersection," and the remarks on the Warren truss will apply also to these.



The Fink truss :

The through bridge, supposed to have sixteen panels :

Every part will receive its maximum strain when the bridge is uniformly loaded.

Let S = the span $A\,B$.
" D = the depth of truss $F\,E$.
" L = length of main suspending rod $C\,E$.
" L' = length of suspending rod $F\,G$.
" L'' = length of suspending rod $H\,I$.
" L''' = length of suspending rod $F\,N$.
" W = total weight of bridge and load.

The strain on centre post $F\,E$ and end post $D\,B = \frac{W}{2}$.

The strain on quarter post $H\,G = \frac{W}{4}$.

The strain on eighth post $K\,I = \frac{W}{8}$.

The strain on sixteenth post $M\,N$ = weight of ½ chord $F\,K$ and ½ of lateral braces.

The strain on suspending links $I\,L$ and $N\,O$ = weight of one panel with load.

The strain on suspending rod $E\,D = \frac{W}{4}\,\frac{L}{D}$.

The strain on suspending rods $D\,G$ and $F\,G = \frac{W}{8}\,\frac{L'}{D}$.

The strain on suspending rods $H\,I$ and $F\,E = \frac{W}{16}\,\frac{L''}{\frac{1}{2}D} = \frac{W}{8}\,\frac{L''}{D}$.

The strain on suspended rods $K\,N$ and $F\,N = \frac{W}{32}\,\frac{L'''}{\frac{1}{2}D} = \frac{W}{16}\,\frac{L'''}{D}$.

The strain on the chord is found by resolving the strains which are transmitted by the tension rods. Then

Strain on chord

$$= \frac{W}{4}\,\frac{\frac{1}{2}S}{D} + \frac{W}{8}\,\frac{\frac{1}{4}S}{D} + \frac{W}{16}\,\frac{\frac{1}{8}S}{\frac{1}{2}D} + \frac{W}{32}\,\frac{\frac{1}{16}S}{\frac{1}{2}D} = \frac{23}{128}\,\frac{WS}{D}.$$

The deck bridge: In this case, the suspending links $N\,O$

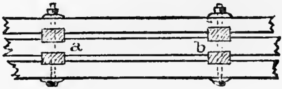
and IL, etc., will be left out. The strain on the chord and tension rods and all the posts except the "sixteenth," $M\ N$, etc., will be the same as before. The sixteenth posts, MN, etc., will be strained by an amount equal to $\frac{W}{16}$.

On the Pennsylvania Railroad, the greatest variable load that can come upon one track is supposed to be 1½ tons per lineal foot, and all bridges are calculated for this. That is, the length of a panel multiplied by 1½ will give the value of 2 W' in tons in the previous statement of the strains in the Howe truss bridge. The uniform load, or weight of bridge, 2W, is taken at ½ a ton per lineal foot of track, multiplied by the length of a panel. The floor beams and track-stringers should be calculated for the greatest concentrated load which can come upon them, which is the weight on a pair of driving-wheels, and amounts to 22,000 pounds. When the floor beams rest on a chord, its resistance must be calculated for the transverse strain so produced, in addition to the strain calculated on the supposition that the load is concentrated at the panel points. The English generally only allow the load to come on the truss at the panel points. In America, however, the advantage gained by supporting the engine on the floor beams in case of a derailment, has been considered sufficient to retain the method of resting them on the chord. It may sometimes be well, if the trusses are far apart, to rest them on a saddle, so as to insure their

bearing equally on the chord, and not merely at the inside edge, when the floor beam deflects.

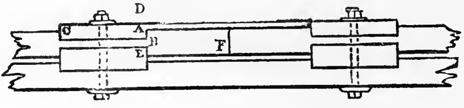
Care should be taken that the resolved strain from a

brace to a chord should pass through the centre of gravity of the section of the chord, and similarly from a strut to a tie. In a Howe bridge, by varying the size of the angle block, the axes of the brace and rod can easily be made to pass through this centre of gravity, that is, intersect there. This same point of intersection of the three strains in a Pratt bridge is the proper position for the pin. In reference to this pin, it may be remarked that in its manufacture the recommendations of Mr. Coleman Sellers in regard to axles should be observed; that is to say, turn it approximately true with a fine feed, and finish with a coarse feed revolving rapidly. This obviates the effect of the wear of the tool, which would otherwise make the surface conical instead of cylindrical. In Howe truss bridges, the upper chord is formed of several sticks of timber, which are made to act together by "keys" being notched into them.



The distance apart of the keys, *a b*, should bear the same relation to the width of one of the sticks composing the chord, as the length of one panel bears to the total width or dep
chever to the least)
of the chord. The depth of the notch is made $\frac{1}{8}$ the width of the chord. The strength of the upper chord in the panel should be calculated by Gordon's formula for long columns. (See "Trautwine's Pocket Book.") It is only necessary to abut the several sticks against each other, without splicing them, making them break joint, however, so that there will not be more than one joint in a panel. The

lower chord sticks have to be spliced, and the very common practice is to make the splice too weak.



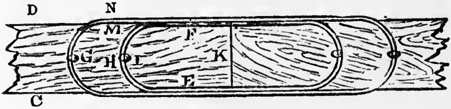
This is, perhaps, the commonest form of such splice.

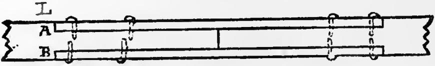
The notch $A\ B$ is generally too small, and bridges are often seen in which it is crushed. The proper relation between the parts of this splice is the following:

Let c = the crushing resistance of the wood = 5,000 lbs. per square inch for pine.
" t = the tensile resistance of the wood = 10,000 lbs. per square inch for pine.
" s = the shearing resistance of the wood = 600 lbs. per square inch for pine.
Then $c \times A\,B = t \times B\,E = s \times A\,C = s \times B\,F$.

For pine, we see that $A\ B = 2\ B\ E$, or less than one-third of the thickness of the stick is available, the remainder being cut away. If two splice-pieces are used, however, one on each side, $A\ B$ will equal $B\ E$ and just two-thirds of the chord will have to be cut away. The splice-piece and keys are generally made of oak, or other hard wood. This is objectionable, since wood rots much more rapidly when it is in contact with a different species. A much better splice for the lower chord is that recommended by the late Mr. B. H. Latrobe, in the *Railroad Gazette*, vol. 10, p. 501. A flat iron link is set into the chord on each side. As a very small breadth is necessary to give the iron sufficient shearing resistance corresponding to the part $A\ C$, in the above wooden splice, sufficient space is

left on the chord to put two or more additional surfaces on the link to withstand the crushing force.





The following are the proper relations for determining the sizes :

$A\,B \times C\,D \times$ tensile resistance of the wood should equal $(C\,D + E\,F) \times A\,L \times 2 \times$ crushing resistance of the wood, and should also equal

$(G\,H \times C\,D + I\,K \times E\,F) \times 2 \times$ shearing resistance of the wood, and should also equal

$A\,L \times M\,N \times 8 \times$ tensile resistance of the iron bands.

Other forms of splices may be seen in the *Railroad Gazette*, vol. 10, p. 573, in an article by Mr. Geo. L. Vose.

The amount that the angle blocks are notched into the chord is a point to which not sufficient attention has been given in many existing bridges. They should have sufficient bearing surface to resist the crushing strain transmitted from the brace to the chord. It fortunately happens that this is greatest at the ends, where there is an excess of material in the chords, as they are made of the same section throughout, generally, in wooden bridges. The necessary amount of notching, of course, diminishes to the middle.

The nuts at the ends of the rods in a Howe truss bridge rest on wrought-iron pieces, which act the part of washers to distribute the load over a considerable surface of the

wood, to prevent crushing of the fibre. Cast-iron "tubes" are generally used to transmit the strain from the rod to the angle block. They are ordered about a half-inch shorter than the depth of the chord, to allow for shrinkage in the latter. The rods are generally ordered of such a length that they will project beyond the nut a distance equal to half the diameter of the rod. The joints of the chords, especially those of the lower chord, should be painted with red lead.

Among wooden bridge builders the rule for getting the camber is to make the upper chord as much longer than the lower one as the camber is to be. This additional length is divided up among the different panels in the framing.

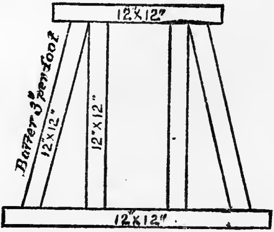
Lateral and diagonal bracing is recommended to be of sufficient strength to resist a pressure of wind of 30 pounds per square foot of truss and train. It is generally made of the Howe or Pratt truss form, and since the strain may come upon it in either direction, the braces and counters are of the same size, acting alternately as one or the other, according to the direction of the wind.

Bridge superstructure: On the Pennsylvania Railroad, roadway bearers of white pine, 8 × 14 inches, are placed two and a half feet apart, centre to centre, resting on the chords and notched half an inch on them. The chord must be calculated to resist the transverse strain thrown upon it by these roadway bearers, in addition to the strain obtained from the strain sheet. Track stringers of white oak, 6 × 12, are bolted to the roadway bearers by one-inch bolts, with flat heads, one bolt to each intersection with bearer. The rails are spiked to the stringers.

For bridges of twenty-feet span, wrought-iron built I-beams of 12 inches depth are used, two to each rail. On these cross-ties, 6 × 8, 7½ feet long, are notched one inch, spaced two feet apart; a stringer, 6 × 12, notched half an

inch, and four feet longer than the iron beams, rests upon the cross-ties, and supports the rails.

Back-wall plates, 6 × 12 : The coping should be strong enough to resist the pressure without wall-plates, using a cast-iron shoe $1\frac{1}{2}$ inches thick.



Trestle-work : The above is the usual form. The "bents" should be well braced together with 6 × 12 stuff, and placed about 10 feet apart. When more than 15 feet high, make it in two or more stories. The posts are generally mortised into the cap and sill pieces. In such cases if the mortise for the lower tenon is not cut entirely through, a hole should be bored to let the water out which will collect in it. Some engineers consider it better to cut no mortises or tenons at the lower end, but to make the connections with wooden dowel pins, two to each post, to prevent twisting. These should be large enough to fit tightly in a three-inch hole. The inclined posts should be cut off square, and rest in shoulders cut in the cap and sill. Iron straps may then be used to keep all secure.

When a mortise and tenon are used, the width of the tenon may be made from one-third to one-fourth the width of the stick. A tree-nail passes through both mortise and tenion, to hold them secure. It is usual to bore the holes for this, not directly opposite to one another, but that in

the tenon a little nearer the shoulder than would be opposite that in the mortise. This will make the driving of the pin draw the post tightly against the cap. In a trestle designed by the writer for carrying water-pipe, a tenon 5 inches long on a 6 × 8 stick, in a cap of the same size, with a pin $1\frac{1}{2}$ inch in diameter, was made to draw $\frac{1}{8}$ of an inch, which proved to be a very little too much, as it cracked some of the caps ; not enough, however, to destroy any or make them unfit for their duty. However, a draw of $\frac{3}{32}$ would have been better for this size of timber. One-eighth draw would do for 12 × 12 sticks.

MASONRY.

In masonry, the two important points required are to have good beds to the stones, and to have a good bond. When not closely watched, masons working for contractors will put "nigger-heads" into the wall, that is, stones from which the natural rounded surface of the stone or boulder has not been taken off. Each course should be made level before beginning the next one. There should be plenty of headers, to run into the wall as far as possible. A trick of the masons is to use "blind headers," or short stones that look like headers on the outside, but do not go deeper into the wall than the adjacent stretchers. When a course has been put on top, they are completely covered up, and, if not suspected, the fraud will never be discovered unless the wall shows its weakness. The headers may taper off at the back in their width, but should retain their depth throughout. Rankine recommends that one-fourth of the face of a wall should consist of headers, whose length should be from three to five times the depth of a course. Some engineers prefer masonry laid dry, as it requires a superior class of work, and imperfections are more easily detected. For railroads, however, it is apt to be shaken loose by the motions of the trains.

Mortar is made of a mixture of $1\frac{1}{2}$ bushels of lime to 3 of sand, the lime to be slacked (one part water to one of lime) immediately before using, before the sand is put in; the sand to be sharp, and better if the grains are large (coarse). This amount will lay a perch of stone. Vicat says the best proportions are $2\frac{4}{10}$ of sand to 1 of lime (Rankine). If cement is used, not too much water should be mixed with it. It is found that the cement becomes hardest if just enough water is mixed to make it moderately dry, but capable of being finished and smoothed off with a trowel. The proportions are one of water to four of cement by measure. Cement used neat is liable to crack. For this reason, and the sake of economy, it is mixed with an equal measure of sand, the larger and sharper the better. Above the water line, two parts of sand to one of cement may be used. For mixing cement and sand, an old wine barrel is better than a mortar box. In the latter, it is difficult to prevent the sand from floating on top; that is, it is more difficult to get them thoroughly mixed.

It used to be the custom to lay about four inches from the face in cement mortar thick, and to grout the remainder with the same mortar, with its consistency so reduced by water that it would run into the interstices. As it is found, however, that this excess of water injures the quality of the cement, the practice is being given up.

FOUNDATIONS.

The best foundation is rock. Rankine says the crushing strain of limestone and sandstone is from 3,000 to 8,500 pounds per square inch, and granite 10,000 to 13,000. He says the actual pressure should in no case exceed one-eighth the crushing strain. He likewise says that foundations in gravel, hard clay, and sand are usually loaded with from 2,500 to 3,500 pounds per square foot. At Nantes, 17,000 on sand caused some settlement. Mr. H. Leonard, in

Engineering, Vol. 20, p. 103, says that, from the result of actual experiments in India, alluvial soil will safely bear 2,240 pounds to the square foot. He says the depth of such foundations should not be less than four nor more than eight feet. The offsets of the foundation should spread at an angle of 45 degrees, and no step should be less than 18 inches high; if less, it will break off. Sir Charles Fox says his experiments show that alluvial soil will bear 1,680 pounds per square foot. Rankine says the usual rule for spreading the foundation of a wall is to make the breadth of the base $1\frac{1}{2}$ times the thickness of the body of the wall in compact gravel, and twice the thickness in sand and stiff clay.

The foundation, especially in sand and alluvial soil, should be kept from the effects of running water. This may sometimes be avoided by "rip-rapping" round the foundation.

A common way of building on a gravel foundation in streams where the water does not exceed five feet in depth, is to build on two courses of 12×12 inches squared timber, laid close, at right angles to each other, and spiked at each intersection. This is floated in place, and the masonry built until it sinks. For deeper water, there would be a risk of upsetting before reaching the bottom, and guide piles must be driven on the outside. Foundations on gravel or rock, in water, are often built on cribs. A framework, the size of the crib, should be floated to the proper place, and soundings taken all round it at intervals of about three feet, with some intermediate ones across. The bottom of the crib is then shaped to the surface given by the soundings, and so will have an even bearing. The crib is made in open cells, about six feet square, with a floor at the bottom to hold the loose stones which are filled in to sink it. The outside is covered with 12×12 squared sticks, fitting close, laid horizontally. Where the sticks forming the

cells come through the sides, they are dovetailed to them, and spiked besides. All these side sticks are spiked together with spikes which are long enough to go through three of them, so that each one is spiked to the two below.

When the bottom is a soft mud, piles must be resorted to for a foundation.

PILE DRIVING.

Weisbach's formula:

$$L' = W\left(\frac{W}{W+W'}\right)\frac{h}{d}$$

where $W =$ the weight of the ram in pounds.
$W' =$ the weight of the pile in pounds.
$d =$ the depth which the last stroke drives the pile in inches.
$h =$ the height of fall in inches.
$L' =$ the load which the pile will just bear in pounds.

The Dutch engineers use a similar formula, except that they use for d the average penetration per blow, got by taking the whole penetration, in, say, 100 blows and dividing by 100. They also use a factor of safety of $\frac{1}{6}$.

If W' is supposed to be so small in comparison with W that it may be neglected, and a factor of safety of $\frac{1}{8}$ is taken, we have Sanders' formula:

$$L = \frac{W h}{8\, d,}$$

where L is the safe load the pile will bear.

Rankine's formula, supposing the pile to be sustained by the friction on the sides, is

$$\sqrt{\frac{4ESWh}{l} + \frac{4E^2S^2d^2}{l^2}} - \frac{2ESd}{l,}$$

where $E =$ the modulus of elasticity of the pile.
$S =$ the sectional area of the pile in inches.
$l =$ the length of the pile in inches.

We may take $E = 1{,}440{,}000$.
$S = 1\frac{1}{2}$ square feet $= 216$ square inches for an average.
$l = 30$ feet $= 360$ inches for an average.

Then the formula reduces to

$$L' = 1{,}859 \sqrt{Wh + 864{,}000\, d^2} - 1{,}728{,}000\, d.$$

Rankine recommends a factor of safety of 5, which will reduce the equation to

$$L = 372 \sqrt{Wh + 864{,}000\, d^2} - 345{,}600\, d.$$

Trautwine gives (reducing the values of his letters to the same measure):

$$L' = \frac{27\, W \sqrt[3]{h}}{1 + d} \text{ for the extreme load, and}$$

$$L = \frac{9\, W \sqrt[3]{h}}{1 + d} \text{ for the safe load.}$$

Rankine states that, according to the best authorities, the piles should be driven until $d = \frac{1}{150}$ of an inch, while Trautwine says the French consider it sufficient for d to equal $\frac{1}{75}$ of an inch. Rankine's formula takes a simpler form when h is expressed in feet. It then bears some resemblance to the formula given by McAlpine; the latter, however, being evidently derived from wrong hypotheses.

Rankine's formula when h is in feet, and $d = \frac{1}{150}$ becomes

$$L' = 80 \left\{ 80 \sqrt{Wh} - 144 \right\} \text{ for ultimate load, and}$$

$$L = 16 \left\{ 80 \sqrt{Wh} - 144 \right\} \text{ for safe load.}$$

If W is expressed in tons, an approximate formula is

$$L' = 135 \sqrt{Wh} \text{ for ultimate load, and}$$

$$L = 27 \sqrt{Wh} \text{ for safe load.}$$

Rankine gives, as the limit of safe load on piles which reach firm ground, 1,000 pounds per square inch of head, and for the safe load on those which rely only on the friction of the mud against the sides, 200 pounds per square inch of head. He says the diameter should never be less than $\frac{1}{20}$ of the length. This probably refers only to piles resting on a hard stratum. Some of the piles supporting

the bridges in the Hackensack marshes are 70 feet long, but *not* $3\frac{1}{2}$ feet in diameter. The piles of the bridges which carry the Philadelphia, Wilmington & Baltimore R. R. over the Gunpowder River never reached a solid bottom. They are very long, however, and have proved perfectly satisfactory. Rankine says the best material is elm, and they should be driven butt downward. The ends should be sharpened to a point, whose length is $1\frac{1}{2}$ times the diameter. The piles of the South Street Bridge, Philadelphia, were not sharpened, but were cut off square, to increase the bearing surface.

The bearing power of discs on iron piles in sand is five tons per square foot, according to Brunlees.

For driving piles through boulders and gravel, a heavy ram and small fall is the best. For example, a ram of 50 cwt. and a fall of 8 to 10 feet. For driving through sand, the blows should be delivered rapidly, so that the sand should not have time to compact itself about the pile in the intervals. A gunpowder pile driver is good for this purpose. McAlpine states that the surface friction in driving cast-iron cylinders 6 feet in diameter, through rocky gravel, was one-half a ton per square foot. Gaudard gives the friction between cast-iron cylinders and gravel at 2 to 3 tons per square yard for small depths, and 4 to 5 tons per square yard for depths of 20 to 30 feet. He also says that piles at La Rochelle, in soft clay, can support 164 pounds per square foot of lateral contact, and at Lorient, in silt, 123 pounds. According to some observations made by Mr. Stauffer at the South Street Bridge, in Philadelphia, the frictional resistance of mud on cast-iron cylinders was only $46\frac{1}{2}$ pounds per square foot of surface.

TRACK-LAYING.

After the road is brought to sub-grade, the centre line is re-run, and stakes are set on each side of the road-bed at $4\frac{1}{2}$

feet off on a single-track road, and 100 feet apart, except on curves sharper than 3 degrees, where they should be 50 feet apart. These stakes are put one-foot above the sub-grade, and give the top of the ballast. On curves, the outer one is elevated $\frac{1}{10}$ of a foot for each degree of curve above the inner one, which carries the grade. This gives the elevation of the outer rail $\frac{1}{2}$ an inch for each degree of curve, which is what it ought to be, supposing a speed of 30 miles an hour. The rule for track-layers to have when there are no stakes set, is, the elevation is equal to the middle ordinate of a chord of 48 feet of the curve.

The track-layer places a wooden straight-edge, 8 inches wide, on the stakes at two consecutive stations, and has two pieces of wood, 8 inches long, held upright on a tie at the places where the rails come. The tie is then driven down until the visual plane across the straight-edges just touches the tops of the blocks. Having set three intermediate ties in this way, the remaining ones are set with a straight-edge 15 feet long, laid on two of the ties already set. All the ties having been set, the half-gauge is measured off at the stakes, and the rail spiked fast, the portion between two stakes being lined by eye. One line of rails having been spiked, the other is spiked with a gauge-rod applied at every tie.

For bending rails to a curve, they are allowed to fall on two supports, placed at some distance apart, and the stored-up energy due to gravity produces the required result. (See *The Engineer* for Aug. 24, 1877, p. 139.)

A fall of 2 feet 2 inches on supports 18 feet apart gives a curve of $\frac{3}{16}$ of an inch, corresponding to a curve of 2,970 feet radius; similarly,

A fall of 2 feet 8 inches gives a ver. sin. of $\frac{3}{8}$ of an inch, corresponding to a radius of 1,980 feet.

And a fall of 3 feet gives a ver. sin. of $\frac{9}{16}$ of an inch, corresponding to a radius of 990 feet.

For sharper curves, a rail-bending machine must be employed.

SWITCHES.

To find the distance from the point of a switch to the point of the frog on a curve:

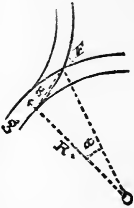
The switch may curve to the outside or the inside of the curve.

The formulas for the distance are the same.

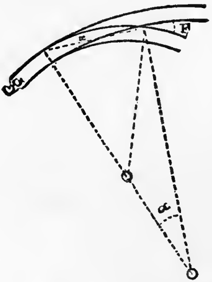
$$tan.\ \tfrac{1}{2}\,\alpha = \frac{g}{2\,R\,tan.\ \tfrac{1}{2}\,F} = \frac{g}{4\,n\,R}\ \text{(where } n = \text{the number of the frog).}$$

$$x = \frac{g\ cos.\ \tfrac{1}{2}\,\alpha}{sin.\ \tfrac{1}{2}\,F.}$$

The value of the radius of the turnout differs in the two cases as below.

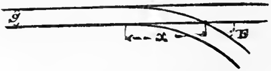


$$R = \frac{\tfrac{1}{2}\,x}{sin.\ \tfrac{1}{2}\,(F - \alpha)} - \frac{g}{2.}$$



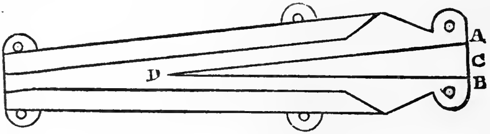
$$\text{Radius of turnout} = \frac{\tfrac{1}{2}\,x}{sin.\ \tfrac{1}{2}\,(\alpha \pm F)} \mp \frac{g}{2}\ \begin{cases}\text{upper signs for inside.}\\ \text{lower signs for outside.}\end{cases}$$

To find the distance from the point of switch to point of frog on a tangent:



$$x = g\,\frac{1 + cos.\ F}{sin.\ F} = \frac{g}{tan.\ \frac{1}{2} F.}$$

It is usual to designate frogs by numbers which express the relation between the base and altitude of the triangle forming the point of the frog.



Thus, a No. 8 frog is one whose length is 8 times the base; $D\ C = 8\ A\ B$.

The above equation then reduces to

$$x = 2\,g\,n,$$

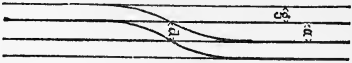
where $n =$ the number of the frog.

The radius of the turnout is $= \frac{x}{sin. F} - \frac{1}{2}\,g.$

For a No. 8 frog, $F = 7°\ 9\frac{1}{4}'$. It is the usual practice to spike down 5 feet on each side of the frog straight, or, calling the distance from point to end of frog two feet, there would be 12 feet straight. The g in the formula (for a 4 feet 9 inches gauge) would be reduced to 3 feet $10\frac{1}{2}$ inches. In this case, then, $x = 62$ feet and $R = 495.72$, or about an 11° 35′ curve. Five feet of the switch rail is spiked fast. In order to have a throw of $5\frac{1}{2}$ inches, the switch rail should be 27 feet long. The distance from the movable end of the switch rail, or point of switch, to the

point of the frog is, then, 47 feet. This is an ordinary switch on railroads.

To find the distance from frog to frog on a crossing :



Call the distance from point of frog to point of tangent $= c$.

The distance measured on the track from frog to frog :

$$e = \frac{a}{tan.\ F} - \frac{g}{sin.\ F} - c\ cos.\ F.$$

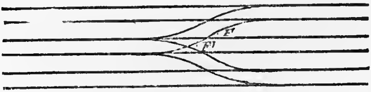
Then,

$$d = \sqrt{e^2 + a^2}$$

For a No. 8 frog, when $g = 4\frac{3}{4}$, $a = 7\frac{1}{4}$, and $c = 7$,

$$e = 12.67,$$
$$d = 14.60.$$

To find the proper angle for the middle frog in a three-throw switch :



$$Ver.\ sin.\ \tfrac{1}{2} F' = sin.^2\ \tfrac{1}{2} F.$$

When two No. 10 frogs are used, we find $F' = 8°\ 6'$, and the third frog should be a No. 7. When two No. 8 frogs are used, the other should be a No. 5.64, or, say, 6.

Bill of crossing lumber, single switch :

3 ties	$9\frac{1}{2}$	feet	long.
2 "	10	"	"
2 "	$10\frac{1}{2}$	"	"
2 "	11	"	"
2 "	$11\frac{1}{2}$	"	"
1 "	13	"	"
5 "	14	"	"
2 "	15	"	"
1 "	16	"	"

1 switch tie......15 feet long, 16 inches wide.

Bill of crossing lumber, double connection :

6 ties	$9\frac{1}{2}$	feet long.
2 "	10	" "
4 "	$10\frac{1}{2}$	" "
4 "	11	" "
4 "	$11\frac{1}{2}$	" "
2 "	12	" "
16 "	19	" "

2 switch ties ....15 feet long, 16 inches wide.

Bill of crossing lumber, triple connection :

2 ties	9	feet long.
3 "	10	" "
2 "	11	" "
2 "	12	" "
3 "	13	" "
1 "	14	" "
2 "	15	" "
1 "	16	" "
3 "	17	" "
3 "	18	" "
4 "	19	" "
2 "	20	" "

1 switch tie......15 feet long, 16 inches wide.

CROSS TIES.

These should be hewed (not sawed or split) on two sides, cut square at the ends, and stripped of the bark before delivery. They should be $8\frac{1}{2}$ feet long and 8 inches thick. Three-fourths of them should measure not less than 8 inches across the hewed surfaces, and one-fourth not less than 10 inches. They should be piled in square piles of about 50 each, the ties crossing each other at right angles in alternate layers. Each pile should be separated from the rest, so that a man can pass around each one to inspect the ties.

Public road crossings at grade :

The space between the tracks is covered with plank, $3\frac{5}{8}$

× 8 inches, 16 feet long, spiked to the ties, and leaving 4 inches clear by the rail for the wheel flanges. Planks are also spiked to the ties on the outside of each rail.

RAILS.

A width of 4 inches is sufficient to prevent the rails from cutting into oak ties, and $4\frac{1}{2}$ inches for chestnut ties, when not spaced more than $2\frac{1}{2}$ feet apart. If the base is made more than this, the difficulty of bending the rails to a curve becomes an objection. The stem of an iron rail need not be more than one-half an inch thick, nor that of a steel rail more than $\frac{7}{16}$ of an inch. 60-pound rails are made ~~$4\frac{1}{2}$~~ inches 4 1/4
high, 50-pound 4 inches, and those under 50 pounds $3\frac{1}{2}$ inches. (See *Engineering*, Vol. 18, p. 369.)

WATER STATIONS.

Passenger engines on the Middle Division of the Pennsylvania Railroad, where the grades are very light, run at a rate of 35 miles per hour with seven cars ; and, when making frequent stops, one tank of water, containing 2,400 gallons, lasts for $2\frac{1}{4}$ hours, or 78 miles. The engines, however, take in water, actually, every 45 miles. A freight train on the same division, with a full tank, can run at a speed of $14\frac{1}{2}$ miles an hour for 2 hours 50 minutes, or $41\frac{1}{2}$ miles with one tank of water. As, however, they have to stop at shorter intervals to allow passenger trains to pass, or to pass each other, they utilize the time of waiting in filling their tanks. On the Mountain Division of the same railroad, freight trains with a full load on an almost continuous grade of $1\frac{9}{10}$ per cent., use a tank full of water, containing 3,000 gallons, in 1 hour 15 minutes, or in going 15 miles. It is thus seen that 15 miles is the extreme distance apart for water stations with grades of two feet in a hun-

dred, while 40 miles would do with very light grades. It would be well, however, if water is plenty, to have them every 10 miles, or oftener.

In a hilly country, streams can generally be dammed up, which will give a gravity supply. The outer slope of the dam may be built of stone, like a retaining wall, or may be of earth at its natural slope. The inner slope should be at the natural slope of clay in water, which is 3 to 1. There should be a layer of good clay on the inside, two feet thick. Cast-iron pipe, 6 inches in diameter, is used to convey the water from the dam to the track. This should have a fall of at least 1 or $1\frac{1}{2}$ feet per 100 for 1,000 feet from the dam. For the remaining distance, if the water is brought so far, the fall had better be not less than .333 per 100. If, however, it is impossible to give it a continuous down grade, it may be laid undulating, so long as no portion rises above the "hydraulic grade line," as defined in "Trautwine's Pocket Book." If it is so laid undulating, it will be necessary to place an air cock at every "summit," and a mud cock (blow-off cock) at every "valley." At the track, a "stand pipe" or "plug" is placed, which rises to an outlet 9 feet above the rail. A valve controls the outlet, within reach of the engine-driver. A piece of rubber hose, 7 inches in diameter, 10 feet long, is fastened on the end of the pipe, to insert into the opening in the tender.

It may often happen that a dam cannot be made, or there is not enough water in the stream to furnish a continuous supply. A tank is then placed at the side of the railroad. This is a tub made of white pine, 18 feet in diameter at the bottom, and 17 feet at the top, 8 feet deep. The bottom is 3 inches thick, and the staves $2\frac{1}{2}$ inches thick. There are 6 iron hoops, $\frac{1}{4} \times 3$ inches; two placed close together at the base, and the others at intervals increasing toward the top. The bottom is let into a groove in the staves, but the ends of the staves are let into the floor, so that the bottom bears

over its whole surface on the floor. The tub is supported on three trestles of 10 × 10 inches stuff, placed 6 feet 6 inches apart, on walls 18 inches thick, built parallel to the track, and finished off one foot above the rail. On these trestles, joists 4 × 12 inches are placed one foot apart, which support the floor of two-inch stuff, on which the bottom of the tub directly rests. Where a greater supply is required, or a more permanent structure, and an adjacent hill permits it, stone reservoirs are made 40 feet in diameter and 8 feet deep. They are built below the surface of the ground. The walls are built of common mortar, with a lining of brick well wet and thoroughly bedded in cement. The bottom is covered with a layer of stones about the size of a walnut, 4 inches deep, and made into a concrete with cement; and when it is set, another layer of the same thickness is put in. These reservoirs are covered with a house.

Where a gravity supply cannot be obtained, water must be pumped into the reservoir with a steam engine or windmill.

Six-inch pipe, of a thickness of $\frac{7}{16}$ of an inch, is made to lie in lengths of 12 feet. Each joint requires 8 pounds of lead and a quarter of a pound of "gasket," or loosely twisted rope, which comes for the purpose.

COALING STATIONS.

A freight engine with its load, on very light grades, consumes about 160 bushels of bituminous coal in going 131 miles. This will give some basis for calculating the distances at which coaling stations must be provided.

PASSENGER STATIONS.

Description of Cresson Passenger Station, Pennsylvania Railroad:

One story high, 70 × 40 × 12 feet high, with sloping

roof. Posts or "studs" are set 6 × 7 inches at the corners, and 5 × 6 inches at points $5\frac{1}{2}$ feet apart. These are braced by horizontal pieces, 3 × 4 inches, placed about 4 feet apart, except at the windows and doors. Diagonal braces, 4 × 6 inches, are placed at the upper corners, framed into the posts and a beam, 6 × 7 inches, which forms the tie beam of the roof truss. The latter is a king post of 6 × 6 inch pieces, with secondary king-post trusses, abutting toward the centre against a straining beam, all 4 × 6 inches. The ridge pole is 2 × 10 inches, with purlins 4 × 7, and rafters 3 × 5 inches, spaced two feet apart. Joists, 3 × 10, spaced $1\frac{1}{2}$ feet apart. Flooring, $1\frac{1}{4}$ inches, worked. Roof sheeting, 1 inch. Platform flooring, 2 inches. Platform joists, 3 × $9\frac{1}{2}$ inches. Weather boarding, $\frac{7}{8}$ of an inch thick, 9 inches wide, with $\frac{7}{8}$ of an inch stripping, 2 inches wide. Partition of $\frac{7}{8}$ of an inch stuff. Plastering lath, 3 feet long.

Water station at Gallitzin, Pennsylvania Railroad:

"Balloon frame," 22 feet 8 inches by 22 feet 8 inches by 18 feet 6 inches high. Wall plates, 3 × 8 inches. End posts, 4 × 4 inches. Studs, 2 × 4 inches, 18 inches apart. Diagonal pieces, $1\frac{1}{2}$ × 3 inches, 2 feet 6 inches apart, measured vertically. Rafters, 2 × 6 inches. Ridge pole, 2 × 8 inches. Joists, 4 × 12 inches. Siding of $\frac{7}{8}$ of an inch worked boards, tongued and grooved. Sheeting, ditto. Slate roof.

It may here be remarked that when a plank is nailed to a post or joist, or other wooden substance, a nail is used, of such a length that it will go twice as far into the post or joist as the thickness of the plank. Thus, for $\frac{7}{8}$-inch stuff, use $2\frac{1}{2}$ inches long or 8 penny nails, for 1-inch stuff use 3 inches long or 10 penny nails.

TELEGRAPH LINE.

The number of poles to the mile varies from 26 to 42.

The size of wire varies from 320 to 380 pounds per mile. The poles should not be less than 5 inches in diameter at the top, nor less than 25 feet long. If green, they should be charred 5 feet from the bottom. If any are split at the lower end, the parts should be nailed together before putting in the ground; otherwise, the spring of the wood will prevent the earth from packing around them. The cross-arms are made of 3 × 4 inches, 3 feet long, white pine, painted white, one bolt for each cross-arm, ½ inch diameter, 8 inches long, square head and nuts, and wrought washers.

Sixty miles of line will require at each end a battery of 15 cups (Grove's). These cups require to be re-charged twice a week. A battery of 30 cups requires 1 carboy or 200 pounds of nitric acid, 25 pounds of sulphuric acid, and 1 pound of zinc per cup, every month.